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Nitrate Occurrence In U.S. Waters (and Related Questions)

A Reference Summary of Published Sources from an Agricultural Perspective

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Prepared by John Fedkiw
USDA Working Group on Water Quality

Preface

Development of this reference summary of published information on nitrate occurrence in U.S. waters and related questions was undertaken in 1990 by the USDA Working Group on Water Quality. The summary is meant to provide the U.S. Department of Agriculture (USDA) a broad perspective on the proportions of the problem of ground and surface water and estuary contamination associated with nitrate from agricultural sources. The formal assessment of water quality conditions is primarily the role of the U.S. Geological Survey and the U.S. Environmental Protection Agency at the Federal level and primarily of the States at the local level. However, the USDA uses the information from such assessments along with our own research to establish the dimension of the problem and to shape the direction of our program and project priorities. Our aim is to help farmers and rural residents solve water quality problems where they occur or where they can be predicted working with other Federal agencies and the states, and to help farmers operate in a manner that minimizes or prevents pollution from agricultural sources.

The summary was designed and compiled by Dr. John Fedkiw, Associate Director, Office of Budget and Program Analysis and staff member of the USDA Working Group on Water Quality. The Nitrate Subcommittee of experts identified the sources of nitrate information for the summary and provided technical reviews. The Nitrate Subcommittee participants included representatives from the following agencies:

U.S. Department of Agriculture
- Office of Budget and Program Analysis
- Agricultural Research Service
- Cooperative State Research Service
- Economic Research Service
- Extension Service
- Soil Conservation Service

U.S. Environmental Protection Agency

U.S. Department of the Interior
- Geological Survey

Tennessee Valley Authority

U.S. Department of Commerce
- National Oceanic and Atmospheric Administration

Leopold Center for Sustainable Agriculture at Iowa State University

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Contents

	Page
Introduction	1
Question 1. To What Extent Is Nitrate-N Found in U.S. Waters?	2
Executive Summary	2
Ground Water	3
U.S. Geological Survey	3
Monsanto Survey	5
EPA National Survey of Drinking Water Wells	6
Surface Water	6
Human Exposure to Nitrate-N in Public Drinking Water Systems	7
Estuaries	9
State Data and Assessments	11
Nebraska	11
Arkansas	12
North Carolina	12
Appalachia and Southeast	12
Washington	13
California	13
Pennsylvania	13
Minnesota	13
Ohio	14
Iowa	15
Question 1 Appendix	
Table 1	16
Table 2	17
Table 3	18

	Page
Question 2. What Are the Seasonal and Longer Term Patterns and the Influences of Other Factors Associated With Nitrate Concentration in Wells?	19
Executive Summary	19
Seasonal Variation	19
Long-Term Trends in Nitrate Concentration	20
Nebraska	20
Other Studies	21
Nitrate Concentration by Well Depth	22
Other Factors Influencing Occurrence of Nitrate Contamination	22
Iowa Analyses	22
Nebraska Analyses	23
Kansas Analyses	24
Minnesota Analyses	25
Pennsylvania Analyses	26
South Dakota Analyses	27
The Occurrence and Influence of Denitrification	28
Question 3. What Is Known About the Human Health Effects of Nitrate in Water?	29
Executive Summary	29
Methemoglobinemia in Infants	29
Other Effects	30
Question 4. What Is Known About the Environmental and Livestock- Related Effects of Nitrate in Water?	31
Executive Summary	31
Environmental Effects	31
Livestock Effects	32
References	33

Nitrate Occurrence in U.S. Waters (and Related Questions)

A Reference Summary of Published Sources From an Agricultural Perspective

Introduction

This summary of nitrate occurrence in U.S. waters and water wells and related questions is based largely on the published data, analyses, and reports available in the U.S. literature. Major sources include the U.S. Geological Survey, the U.S. Environmental Protection Agency, the National Oceanic and Atmospheric Administration, the U.S. Department of Agriculture, various State reports and surveys, symposia and conference papers, independent research papers, and a well survey of the Monsanto Agricultural Products Company.

The information from these diverse sources is not strictly additive due to differences in methodology and study designs. Nor does it fully reflect the dimensions of the problem of nitrate contamination in U.S. waters. Nevertheless, the amount of quantitative information available is substantial and reflects what is known about the distribution and levels of nitrate contamination and the factors influencing its occurrence in U.S. waters and water wells. That information is sufficient to provide a weight-of-the-evidence sense of the proportions of the nitrate contamination problem from an agricultural perspective.

This summary is designed and presented with the weight-of-the-evidence approach in mind. It is organized as a response to the following four basic questions:

1. To what extent is nitrate found in U.S. waters?

2. What are the seasonal and longer term patterns and the influence of other factors associated with nitrate contamination in U.S. waters and water wells?

3. What is known about the human health effects of nitrate in water?

4. What is known about the environmental and livestock-related effects of nitrate in water?

A separate Executive Summary is prepared for each question and is presented immediately following each question. The reference sources and citations are separately listed at the end of the report.

Executive Summary

Ground Water. Information compiled by the U.S. Geological Survey (USGS) clearly shows that the United States has large amounts of potable ground water available for use. Nitrate concentrations in large aquifers furnishing drinking water generally do not exceed the U.S. Environmental Protection Agency (EPA) Federal standard for maximum concentration of nitrate-N in drinking water, i.e., 10 mg/L. USGS water samples for 316 principal aquifers in 46 States indicate that the median level of nitrate-N in 288 of those aquifers (91 percent) does not exceed 3 mg/L; in 27 of the aquifers, it ranges between 3 and 10 mg/L and in one, it exceeds 10 mg/L.

The same USGS data also show that there are 41 aquifers in 20 States for which 10 percent or more of the samples tested had nitrate-N levels above the EPA drinking water standard. These samples indicate there are "hotspots" within these aquifers where the nitrate concentration exceeds the EPA standard. Some of this contamination has been linked to agricultural activity.

The USGS also analyzed the nitrate-N test results from samples collected over 25 years from nearly 124,000 wells in all States. For almost 100,000 of those wells (80 percent), the maximum nitrate-N concentration was 3 mg/L or less. Only 7,900 of the wells (6.4 percent) had a maximum concentration of nitrogen-N greater than 10 mg/L. This number is biased upward due to the use of maximum nitrate level for this analysis where there was more than one sample estimate per well. In addition, USGS data collection is oriented toward testing waters in problem locations and in the case of nitrate, the sampling is heavier in localities where there is a known nitrate problem.

The foregoing USGS data also show that the 20 States with the largest agricultural marketings in 1989 (exclusive of the eight Southeastern Atlantic and Gulf Coast States and Arkansas where nitrate levels are typically low) had a notably higher percentage of wells with nitrate-N concentrations above 10 mg/L than the remaining 30 states: 7.1 percent compared to 3.0 percent, respectively.

A 1987 evaluation by USDA, using the same USGS database, showed that out of 1663 agricultural counties which had nitrate tests from four or more wells, 25 percent or more of the wells in 87 counties (5 percent) had nitrate-N concentrations above 10 mg/L. The greatest concentration of these counties was in the Great Plains States from South Dakota to Colorado and Texas, and in parts of California, Montana, Arizona, Minnesota, Wisconsin, Iowa, Missouri, Kentucky, Tennessee, and Pennsylvania.

A survey of 1,430 randomly selected and sampled drinking water wells in agricultural areas of 26 States, conducted in 1988 and 1989 by the Monsanto Agricultural Products Company, found nitrate-N above 10 mg/L in 4.9 percent of the wells. For wells on farmsteads only, however, the proportion was 10 percent.

The EPA National Survey of Pesticides in Drinking Water Wells, published in 1990, also tested for nitrates. The National Survey statistically selected and sampled the water of 650 public system wells and 700 private wells. Only 1.2 percent of the community wells nationwide contained nitrate-N above 10 mg/L. Among the private wells, only 2.4 percent exceeded the 10 mg/L standard. The median concentration of detectable nitrate-N (0.15 mg/L) in the surveyed wells was approximately 1.6 mg/L.

Surface Waters. For rivers and streams, the national median level of nitrate-N concentration, measured at 383 USGS sampling stations throughout the coterminous United States, was 0.4 mg/L. The 75th percentile level was 0.89 mg/L. Thus, by and large individual station nitrate-N concentrations were below 1.0 mg/L, the approximate optimum level for aquatic life. The upper nitrate-N level at 80 percent of this optimum level is about 2.8 mg/L.

Between 1974 and 1981, nitrogen concentrations increased at 116 stations while they decreased at 27 stations. No significant trends were detected at 240 stations (62 percent). Atmospheric deposition appears to have played a large role in the frequent occurrence of nitrate increases in rivers in the Midwest and Mid-Atlantic regions of the United States.

Estuaries. The increased delivery rate of nitrate to east coast estuaries, the Great Lakes and the Gulf of Mexico has become a concern. For these locations nitrogen loadings increased around a third from 1974 to 1981. This raises the level of concern (even though the base median annual levels of nitrate-N loadings were generally low) because the critical level of nitrogen for healthy, high-quality saline waters in estuaries is lower than for streams. For example, it is estimated to be 0.6 mg/L for the Chesapeake Bay. The upper level for fair quality is only 1.0 mg/L. A low level of nitrogen is a desirable limiting factor to eutrophication in many estuarine environments.

The extent to which agricultural loadings contribute to overall estuarine water quality is generally unknown. Available data for the east coast indicates nitrate loadings into estuaries from agricultural land are extremely variable both in their absolute amount and in their share of the total loadings. Agriculture has been identified as a significant source of nitrate in the Chesapeake Bay. Analyses from the first long-term study of water quality in the Chesapeake Bay indicate that the Bay may recover from excess nutrient levels in a few years— rather than several decades as previously thought— once the total annual nutrient loading is reduced by the goal of 40 percent. Early study results indicate that perhaps up to 90 percent of the nitrogen entering the Bay is cycled out in the same year by bacterial denitrification, plants, fish, and natural water flows.

Ground Water

U.S. Geological Survey. The U.S. Geological Survey (USGS) reported groundwater quality data for principal aquifer areas on a state-by-state basis as of 1986 (USGS, 1988). USGS groundwater samples for 370 of such areas were analyzed for a number of groundwater constituents. A principal aquifer area refers to all or that part of an aquifer lying within the boundaries of the State and serving as a principal source of water supply for communities and locales within that State. An aquifer crossing State boundaries and serving as a principal source of water in two or more States was treated as a separate principal aquifer within each State. Nitrate data were reported for 58,074 water samples taken from 316 principal aquifers in 46 States. This report summarizes the distribution of the median and 90 percentile levels of nitrate, measured as nitrogen (nitrate-N) in the ground water as represented by the 316 aquifers. Since the sampling does not follow a national statistical design, this information should be viewed as indicative of the occurrence of nitrate in ground water across the country rather than as a statistical estimate.

The nitrate-N data for this study generally were obtained from the USGS National Water Data Storage and Retrieval System (WATSTORE), which includes data collected and analyzed by USGS in cooperation with State water agencies. Additional data used were from available State computerized water-quality data bases.

The median number of samples tested per State was 768 and the median number of samples per aquifer was 60. These observations are not random samples by State, region, or Nation since the USGS water sampling program tends to locate projects in suspected or known problem areas and for a variety of purposes in addition to nitrate testing. In addition, the density of well sampling for nitrate is higher in locations where problems of nitrate in water are known to exist.

In 1982, the USGS analyzed 87,000 wells for nitrate concentration, 53 percent out of a total of 164,000 wells sampled for all purposes. In recent years USGS sampling programs have placed greater emphasis on water quality investigations in agricultural areas, so the total of wells tested for nitrate has likely increased (USGS, 1988 and Mattraw, 1991).

The USGS data on nitrate in ground water is voluminous and ought not be ignored but used prudently. Users should recognize that the problem- oriented objectives of USGS sampling of wells and ground water indicate a likely upward bias (compared with random sampling) in the levels of nitrate detected in the sample wells selected for nitrate determinations. Therefore, the analyzed USGS sample data probably involve overestimates of the actual levels of general nitrate contamination and of the frequency or rate of sample well contamination with nitrate above the EPA health advisory level of 10 mg/L for drinking water.

The USGS takes precautions to ensure that its water samples represent the surrounding ground water in the aquifer rather than the standing water content of the well. It does so by pumping out the total water column to be sampled 3 to 5 times and testing for certain characteristics such as temperature, conductivity, and acidity to ensure chemical stability in the water column (Mattraw, 1991).

The results of the nitrate analyses for the principal aquifers indicate that the median level of nitrate-N in 288 of those aquifers (91 percent) does not exceed 3 mg/L. An additional 27 aquifers (8 percent) had median nitrate levels between 3 and 10 mg/L. Only one aquifer (<1 percent), the Sioux Quartzite in southwestern Minnesota, had a median nitrate level above 10 mg/L. The maximum nitrate-N concentration allowed by EPA standards in primary drinking water is 10 mg/L 1/. Most ground water that is not affected by human activity contains less than 10 mg/L as nitrate-N. However, the background nitrate-N levels most frequently considered free of human influence are those less than 3 mg/L. Aquifers with 3.0 to 10.0 mg/L of nitrate-N may and often do reflect human influences, but such elevated levels by themselves cannot be taken as reliable or consistent indicators of human influence.

There are a few isolated areas where natural nitrate-rich deposits cause high concentration of nitrate in ground water. The north-central part of the Las Vegas basin-fill aquifer in Nevada is such an example. The Fort Union geologic formation in North Dakota, Montana, and Wyoming typically has high nitrate levels occurring naturally in shallow aquifers. These aquifers often are lignite coal veins. The high nitrate level results from nitrification of high levels of exchangeable ammonia (NH_4) in the marine shales latticed between the lignite coal veins (Power, et al., 1974).

The frequency distribution of median levels of nitrate-N in the 316 principal aquifers is summarized in table 1. For State-level data on aquifers see appendix table 1.

Table 1. Frequency Distribution of Median Nitrate-N Level in 316 Principal Aquifers (from USGS National Water Summary, 1986)

Median Nitrate-N Level (mg/L)	No. of Aquifers	No. of States	Percent of Aquifers
Less than 0.1	102	27	32.3
0.1 to <1.0	140	40	44.3
1.0 to <3.0	46	19	14.6
3.0 to <10.0	27	11	8.5
10.0 or more	1	1	.3
TOTAL	316	46	100.0

Source: USGS, 1988

1/ The 10 mg/L refers to the nitrogen content of nitrate. The equivalent standard for total nitrate content is 45 mg/L. Where the latter standard is used in papers reviewed here, the numbers are converted to nitrate-N equivalent in this report.

The same USGS data show that there were 41 aquifers (in 20 States) for which 10 percent or more of the samples analyzed had nitrate-N levels above the EPA drinking water standard. These samples indicate that within the boundaries of aquifers with median nitrate-N levels below 10 mg/L there are local areas and wells that exceed the EPA health advisory level. Because nitrate concentrations within an aquifer can and do vary widely, it is difficult to generalize and delineate nitrate pollution problems over large areas. The same data also indicate that such local areas or wells with elevated nitrate concentrations are often associated with local sources of nitrate and that the enriched levels of nitrate are not necessarily widespread within the aquifer. Descriptive data on the aquifers with such local "hot spots" of higher nitrate concentration indicate they are predominantly located in shallow sand or gravel of alluvial or glacial origin. Often the aquifers are unconfined. These factors indicate general high permeability to nitrate and direct access to surface sources.

In some cases, the detailed descriptions of the aquifers suggest agricultural use of nitrogen fertilizers (usually with irrigation) as the source of high nitrate levels. Some of the 41 aquifers do not occur in predominantly cultivated agricultural areas. This suggests that nitrate sources other than applied fertilizers may be involved such as wastes from livestock, dairy, or poultry operations; septic tank effluent; landfills; natural nitrate in elevated levels, and accidents or inadequate precaution in handling fertilizers near well sites, as well as various urban sources.

Table 2 shows the frequency distribution of the 90th percentile nitrate level for sample analyses among the 316 principal aquifers in 46 States. For corresponding State-level data on aquifers see appendix table 2.

Table 2. Frequency Distribution of 90th Percentile Level of Nitrate-N for Sample Analyses Among 316 Principal Aquifers 90th Percentile

Nitrate-N Level in mg/L	No. of Aquifers	No. of States	Percent of Aquifers
Less than 0.1	17	8	5.4
0.1 to > 1.0	66	31	20.9
1.0 to > 3.0	124	41	39.4
3.0 to > 10.0	68	30	21.5
over 10.0	41[1/]	20	13.0
TOTAL	316	46	100.0

1/ Includes one aquifer in Minnesota with median level above 10 mg/L.

In 1985 USGS reported the maximum level of nitrate-N concentration found for 123,656 sampled wells by State (Madison and Brunett, 1986). The nitrate data represented 25 years of USGS sampling and testing and included data from 36,000 wells in Texas from the Texas Natural Resources Information System of the Texas Department of Water Resources.

Where wells had been sampled and measured for nitrate-N concentration more than one time, the study used only those sample data with the maximum measured level of nitrate-N. Thus, there is an upward bias in the reported levels of nitrate-N and in the calculated percentage of wells with the highest reporting category (over 10 mg/L), and a downward bias in the lowest reporting category. The data are stored in the USGS National Water Data Storage and Retrieval System (WATSTORE). For the Nation as a whole, 6.4 percent of the wells sampled had maximum nitrate- N concentrations greater than 10 mg/L and 13.2 percent had concentration between 3 and 10 mg/L.

Among the 50 States and Puerto Rico, the average of the individual State percentages for wells with nitrate-N exceeding 10 mg/L was 4.8 percent, while it was 11.5 percent for wells with 3 to 10 mg/L of nitrate-N. The States with percentages higher than these averages are listed below with their specific percentages. Appendix table 3 provides more detailed data on nitrate concentrations in sampled wells for each of the 50 States and Puerto Rico.

Sampled Wells With Over 10 mg/L of Nitrate-N		Sampled Wells With 3-10 mg/L of Nitrate-N	
State	(Percent)	State	(Percent)
Rhode Island	(36.)	*Puerto Rico*	(32.)
Kansas	(20.0)	Kansas	(34.2)
Arizona	(13.9)	Arizona	(24.4)
Oklahoma	(11.8)	Oklahoma	(24.1)
New York	(11.0)	New York	(29.3)
California	(10.1)	California	(22.5)
Texas	(9.4)	Texas	(14.1)
Minnesota	(9.3)	*Washington*	(18.6
Nebraska	(9.3)	Nebraska	(23.4)
Delaware	(9.1)	Delaware	(25.5)
Illinois	(8.4)	*Wisconsin*	(15.1)
Maryland	(6.8)	Maryland	(22.0)
South Dakota	(6.7)	*Connecticut*	(14.)
Pennsylvania	(5.9)	Pennsylvania	(24.4)
Colorado	(5.7)	Colorado	(17.2)
Iowa	(5.0)	Iowa	(1.4)
		Kentucky	(13.0)
		Idaho	(12.9)
		Maine	(12.2)

Note: Italicized States have less than 5 percent of sampled wells with over 10 mg/L of nitrate-N.

A 1987 study by the USDA Economic Research Service using USGS WATSTORE data analyzed the frequency of well contamination with nitrate-N for 1,663 counties out of 2,324 counties where agriculture was an important activity; 661 agricultural counties with only four or fewer wells in the USGS data base were excluded from the analyses (Nielsen and Lee, 1987). The study reported that 87, or 5.2 percent, of the 1,663 counties had 25 percent or more USGS sampled wells with nitrate-N levels exceeding 10 mg/L. Another 387 counties, or 23.3 percent, had 25 percent or more USGS sampled wells with 3 to 10 mg/L of nitrate-N. The balance of the agricultural counties, 1,189 or 71.5 percent, had nitrate samples with 0 to 3 mg/L. The distribution of the 87 counties with 25 percent or more of the sampled wells indicating 10 mg/L or more nitrate-N was most heavily concentrated in the Central Great Plains States from South Dakota to Colorado and Texas. Other counties were scattered among several States: California, Arizona, Minnesota, Iowa, Wisconsin, Missouri, Kentucky, Pennsylvania, and Tennessee.

This distribution corresponds closely with the State distribution of the 41 aquifers whose 90th percentile level of USGS nitrate-N sample analyses exceeded the 10 mg/L drinking water standard. It also includes 11 of the 16 States in which five percent or more of the USGS sampled wells tested for nitrate had concentrations over 10 mg/L.

Monsanto Survey. In 1990, the Monsanto Agricultural Products Company completed a National Alachlor Well Water Survey in agricultural areas of 26 States. The survey sampled and analyzed nitrate and pesticides in 1,430 randomly selected rural drinking water wells representing an estimated 6 million wells. The minimum detectable level of nitrate for the Monsanto survey was 0.3 mg/L. The analyzed levels of nitrate occurrence in the surveyed wells were distributed as follows:

Nitrate-N Level	Percent
No Nitrate Detected	47.70
Less than 3 mg/L	28.72
3 mg/L but < 10 mg/L	18.73
More than 10 mg/L	4.85
TOTAL	100.00

These findings relate to the water found in the well and are not extendable to the aquifers since the sampled wells were not pumped out before sampling. Often, rural drinking water wells are shallow with depths largely between 10 feet and 100 feet. Monsanto also reported that the frequency of wells with nitrate exceeding 10 mg/L doubled to approximately 10 percent for wells located on farm property (Monsanto Agricultural Products Company, 1990). These wells were essentially located on the farmsteads since they were drinking water wells.

EPA National Survey of Drinking Water Wells. Between 1988 and 1990 the U.S. Environmental Protection Agency (EPA) completed a national survey of the occurrence of nitrate in drinking water wells based on a random sample of 1,300 wells used by community water systems or by private rural residents. The survey represented 94,600 drinking water wells used by 38,300 community water systems and 10.5 million private rural domestic wells. The samples were taken to represent drinking water found in the wells so the results are not extendable to ground water, surface water, or tap water. The minimum detectable level of nitrate-N for the EPA survey was 0.15 mg/L (EPA, 1990a).

The survey reported detectable levels of nitrate-N in 52 percent of the community water system wells and 57 of the private wells. However, only 1.2 percent of the community system wells and 2.4 percent of the private rural domestic wells nationwide were estimated to contain nitrate exceeding EPA's health advisory level (HAL) of 10 mg/L (EPA, 1990b). Thus, the EPA national estimates of the percentage of wells with nitrate exceeding the HAL is less than half that estimated by the Monsanto survey for agricultural areas in 26 States. This difference may be attributed to the fact that States with important agricultural production areas generally have higher percentages of wells with nitrate contamination above the HAL. For example, in the 20 States with the largest agricultural marketings in 1989 (exclusive of the eight Southeastern States on the Atlantic and Gulf Coasts and Arkansas), the average proportion of the USGS wells in the WATSTORE data base with nitrate concentrations above 10 mg/L is 7.1 percent. For the remaining 30 States the average proportion of USGS wells with nitrate exceeding 10 mg/L is 3.0 percent. This average drops to 1.8 percent when the very extreme 36.3 percent for Rhode Island is excluded. For the eight Southeastern coastal States and Arkansas the average State proportion is 1.1 percent.

The median concentration of detectable nitrate in the EPA national random sample of 1,300 drinking water wells was approximately 1.6 mg/L. The maximum detected level in the community wells was 13 mg/L; for domestic wells it was 120 mg/L, indicating an extreme skewness of a relatively few measurements to the very high levels (EPA, 1990b).

Surface Water

Nitrogen concentration in rivers and streams is monitored by USGS at 383 sampling stations throughout the coterminous United States. The stations are part of the National Stream Quality Accounting Network (NASQAN) and the National Water Quality Surveillance System (NWQSS). Nitrate-N levels in streams fluctuate widely over a year, so NASQAN readings are often taken bimonthly. NWQSS readings also include multiple readings per year. The USGS network stations provide a representative overview of water quality conditions in U.S. rivers larger than those of stream order 6. Rivers of the first order are those terminating at an ocean, tributaries to first order rivers are considered second order, and so forth. For 1981 the station-mean concentrations of nitrate-N by percentile levels were as follows (Smith et al., 1987):

Percentile	Nitrate-N in mg/L
25th	0.21
50th	0.41
75th	0.89

By and large the station concentrations of nitrogen were below 1.0 mg/L. Nitrate-N concentration below about 0.3 mg/L is usually a nitrogen- deficient range for aquatic life. Concentrations above 1.0 mg/L may be less than optimum and concentrations of 10 or more mg/L may become inhibiting to freshwater ecosystems. The foregoing relations were expressed as a functional relationship of water quality index over mg/L of nitrate-N in the Battelle report, Battelle Environmental Evaluation System, 1972. The functional curve, with its origin at zero quality index and zero nitrate-N, rises steeply to its vertex quality index of 1.0 at 1.0 mg/L of nitrate-N and then drops, largely as a straight line, to zero quality index at 10 mg/L. The quality index 0.8 is indicated at about 2.8 mg/L of nitrate-N. This functional curve is considered to be generally applicable, although the level of nitrate-N for maximum environmental quality may vary from region to region (Canter, 1979).

Between 1974 and 1981, nitrogen concentrations increased at 116 stations while they decreased at 27 stations. At the remaining 240 stations (62 percent) no significant trends were detected. Upward trends were especially frequent east of the Mississippi River and in the far Northwest. The increases in total nitrogen were strongly associated with several measures of agricultural activity, including fertilized area expressed as a percentage of basin area, livestock population density, and feedlot activity. (Smith, 1987a,b).

Another study of total nitrate-N plus nitrite-N for 345 NASQAN stations during water year 1976 provided more information about the variance of nitrate/nitrite concentrations among stations. Mean concentrations were less than 0.5 mg/L at 85 percent of the stations. Only 10 stations had values above 2.75 mg/L and only one station had an average above 10 mg/L, reported as 10.8 mg/L (Britton et al., 1983).

The use of nitrogen fertilizers increased more than fourfold between 1960 and 1981 to 11.9 million nutrient tons. A major component of this increase was heavier fertilizer applications, including a doubling of per-acre use between 1964 and 1984. Since 1981, the total tons used declined 12 percent to 10.5 million tons in 1988 (Nielsen and Lee, 1987 and Vroomen, 1989).

Agricultural nitrogen may enter surface waters as a result of direct surface runoff and soil erosion activity or through groundwater discharges from unconfined aquifers into streams, especially from shallow alluvial sand or gravel, or glacial residue soils and aquifers. According to the USGS, 40 percent of the average annual streamflow nationwide is from ground water. In humid regions such as the eastern seaboard and north-central region, as much as 90 percent of streamflow may come from groundwater discharge in some seasons (EPA, 1990). The runoff from agricultural fields may be accelerated by tiled soil drainage systems, particularly in periods of heavy rainfall. For example, the relative lack of nitrate contamination of ground water in the eastern Corn Belt can be attributed to the widespread use of tile drains which intercept the nitrate-contaminated recharge and deliver it to surface waters (Spalding and Exner, 1990).

Atmospheric deposition was also reported as a major source of nitrate in surface waters in 1981, generally in the basins of the East and the northern Midwest, particularly in the Ohio, Mid-Atlantic, Great Lakes, and Upper Mississippi Basins. The available data on nitrate deposition rates, combined with trend-estimates for nitrogen oxide emissions, show a general pattern of increasing deposition during the 1974-81 period. (Smith et al., 1987 a,b).

Point sources of nitrogen apparently declined in this period due to major improvements in water treatment but the magnitude of change is unknown. Overall, the indicated upward trends in nitrate appear more related to nonpoint sources than point sources, and, in particular, atmospheric deposition may have played a large role in the frequent occurrence of nitrate increases in rivers in the Midwest and Mid- Atlantic regions of the United States (Smith et al., 1987a). Thus, in surface waters the annual mean levels of nitrate-N apparently seldom exceed 1.0 mg/L. Nitrite concentrations are usually much lower than those for nitrate. Nitrate in lakes and other static bodies of water is likewise generally low due to its rapid use by aquatic biota and to the action of denitrifying organisms. (Wade Miller Associates, Inc., 1990).

Although streams generally have annual mean nitrate-N levels that are supportive of aquatic systems, run-off during periods of heavy rainfall or snowmelt can increase nitrate levels temporarily, depending on available nitrate sources and geography (Smith et al., 1987a and Wade Miller Associates, 1990). For example, the *Des Moines Register* on May 5, 1990, reported that spring rains had "washed large amounts of nitrate from fields into the Des Moines and Raccoon rivers." A similar increase in nitrate levels was reported for the Iowa River on June 2, 1990. It was also reported that intermittent elevated nitrate problems have been persistent for about 45 water systems around the State and that community water works have typically dealt with this problem by mixing ground water with surface water to reduce the nitrate in drinking water to levels below the EPA health advisory level.

Human Exposure to Nitrate-N in Public Drinking Water Systems

Wade Miller Associates, Inc., in 1990 reported national estimates of population exposure to nitrate/nitrite-N in excess of the 10 mg/L in public drinking water supplies to the U.S. Environmental Protection Agency. Out of an estimated 219 million people using public drinking water supplies, approximately 1.7 million are exposed to nitrate-N levels above 10 mg/L. Since public water systems are subject to compliance monitoring and enforcement, the exposure involved may often be transient rather than sustained. However, in a June 1990 report, the General Accounting Office (GAO) stated that some drinking water violations were probably going undetected and unreported, and that enforcement actions by the States were often inadequate (Parry, 1990).

About two-thirds of those exposed, 1.1 million, are served by public water systems using groundwater supply sources. The remaining third, 646,000, are served by public systems using surfacewater sources of supply. The estimates also identify exposure among infants less than three months old as approximately 1.6 percent of the 1.7 million total estimated exposure. Thus, almost 27,000 infants a year are exposed to tap water with nitrate-N levels exceeding 10 mg/L. Of these, 12,600 are estimated as breast fed versus formula fed and are presumably at lower risk.

The foregoing exposure estimates were derived from nitrate occurrence data collected nationally from one-time sample measurements in the 1969 and 1978 Community Water Supply Surveys and the 1978-80 Rural Water Survey conducted by EPA. Only the finished water available at the tap or in the distribution system was sampled and evaluated. In 1969, only nine out of 632 community groundwater supply systems observed (1.5 percent) had nitrate samples in excess of 10 mg/L. These were from small systems serving fewer than 1,000 people. In 1978, only 2 out of 352 community groundwater supply systems observed (0.6 percent) had nitrate-N values exceeding 10 mg/L. Of the 494 rural groundwater supply systems studied during 1978-80, only nine (1.8 percent) had sampled nitrate-N levels above 10 mg/L. The EPA national survey of drinking water wells estimated that 1.2 percent of the community water system wells nationwide had nitrate concentrations above 10 mg/L. The maximum level of nitrate detected in community water system wells nationwide was 13 mg/L (EPA, 1990b).

Exposure in public supply systems is likely to be transient since the National Interim Primary Drinking Water Regulations require compliance monitoring of all public supply systems by the States for violation of public health standards for nitrate in drinking water supplies. Surface water systems may face more transient or seasonal nitrate contamination problems than ground water-dependent systems (Parry, 1991).

Annual monitoring is required for surface water supplies and triennial monitoring for groundwater supplies. The violations reported in the 1990 Federal Reporting Data System (FRDS) are consistent with the survey sample results of the national surveys. However, estimating models based on national survey of groundwater systems predict about twice as many violations as are reported in the 1990 FRDS. Monitoring samples can be repeated but must be averaged for evaluation and reporting purposes. This could account for all or part of the lower exposure for groundwater systems indicated by the 1990 FRDS. Under-reporting or failure of detection, as reported by GAO in its June 1990 Report (cited above) may also be contributory factors. Compliance monitoring and enforcement may not always work effectively for nitrate contamination problems because many systems, particularly small systems that rely on ground water, face what may be called intractable problems from a public finance or economic perspective (Parry, 1991).

National exposure data for rural populations served by private wells is not available. Since rural private wells are typically closer to sources of nitrate contamination, the exposure rate can be expected to be greater than for populations using public water systems for which the exposure rate is less than 0.8 percent for the 219 million people estimated to be using public system water. The implied rural population using private wells is about 31 million. If the exposure rate were the same, the estimated exposure would be 238,700 people. However, if one uses the 2.4 percent of domestic private drinking water wells estimated nationwide by the EPA well survey to exceed the nitrate HAL, a higher rate of exposure is indicated, 744,000.

Estuaries

The rising trends in stream nitrate loads indicate that the delivery rates to east coast estuaries, the Great Lakes, and the Gulf of Mexico have increased as shown in table 3. For proper interpretation, however, it is necessary to relate the percentages in table 3 to the base flow. The median concentration levels at the USGS stream quality accounting and surveillance systems stations can be used as a general reference level for interpreting these percentages. Debate has arisen over the need for nitrogen controls in tributary basins. The increased delivery rate of nitrate to estuaries raises a concern because of the tendency for low levels of nitrogen to be a limiting factor to eutrophication in many estuarine environments (Smith et al., 1987b).

Table 3. Recent Changes in Delivery of Nitrogen to Coastal Areas of the United States 1974-81

Region	Percent Change in Nitrate-N
Northeast Atlantic Coast	32
Long Island Sound/NY Bight	26
Chesapeake Bay	29
Southeast Atlantic Coast	20
Albemarle/Pamlico Sound	28
Gulf Coast	46
Great Lakes	36
Pacific Northwest & California	-5

Source: Smith et al., 1987b

For saline waters of estuaries the nitrogen-N level for healthy ecological conditions is somewhat lower than the 1.0 to 2.8 mg/L for fresh waters. Nitrate-N condition indexes developed for Chesapeake Bay water quality management are as follows:

Condition	Nitrate-N in mg/L
Healthy and High Quality	0.6
Fair	0.6 - 1.0
Fair to Poor	1.0 - 1.8
Poor	Over 1.8

Source: NOAA

These condition indices apply to the tidal-fresh waters of the Bay with salinity levels from 0 to 0.5 ppm. For waters with higher salinity levels nitrogen is more limiting and optimum nitrogen levels are much lower than 0.6 mg/L.

The extent to which agricultural loadings contribute to overall estuarine water quality is generally unknown. However, estimates are available on sources of nitrate loadings for seven estuaries. They provide a picture of the range of variation in the absolute and relative levels of nitrogen contributed by different sources. These are summarized in table 4.

Table 4. Annual Nitrogen-N Discharges in Coastal Counties by Estuary, circa 1982[1/]

Source and Area	Estuary						
	Hudson R. /Raritan Bay	Potomac River	St. Johns River	Albemarle Sound	N. & S. Sante River	Charlest. Harbor	Apalachicola Bay
Land area (sq.mi.)	8,169	2,586	6,500	5,804	709	1,165	2,755
Tot. Discharge (M tons/yr)[2/]	89.9	29.2	15.5	12.9	6.7	2.9	1.1.
	Percent of Total Discharge						
Non-Point							
Agric. Land	14	2	18	20	1	3	60
Forest Land	1	<1	30	<1	0	0	35
Other Nonurban	14	<1	1	0	0	0	0
Urban	6	7	17	5	0	21	1
Point							
Waste Water	38	26	18	4	0	29	4
Industry	4	<1	16	<1	0	47	0
Upstream Areas[3/]	23	64	0	70	99	0	0

Source: NOAA, 1986

[1/] Data are for the estuarine drainage areas (EDAs) within the coastal county boundaries. They include the land and water component that most directly effects an estuary.

[2/] Total nitrogen measured as N.

[3/] Upstream area sources of nitrate discharges are rivers that originate outside of and flow into the EDA areas within the coastal counties and eventually discharge into the ocean. Net upstream discharges result from hydrologic conditions and activities outside the study area in the watersheds feeding streamflows in the coastal county study area.

Table 4 indicates that nitrate loadings into estuaries from agricultural land are extremely variable among estuaries in terms of both their absolute amount and their share of total loadings (NOAA, 1986). Somewhat more information is available on the total inorganic nitrogen concentration in 23 east coast estuaries from Maine through Virginia. Twelve of the estuaries have low concentrations, less than 0.1 mg/L of nitrogen. All but one, Chincoteague Bay, are located along the New England and Long Island Atlantic coast. Three have concentrations greater than 1 mg/L of nitrogen: Merrimack River in Maine, Great South Bay on the southside of Long Island, and the Hudson River/Raritan Bay along the Connecticut, New York, and New Jersey coasts. Eight estuaries including Chesapeake Bay have medium concentrations of nitrogen, between 0.1 and 1.0 mg/L.

Studies are underway to evaluate the relationships between nutrient loadings and measures of water quality (dissolved oxygen levels, benthic productivity, phytoplankton levels) in estuarine waters. Detailed studies in the Chesapeake Bay, for example, indicate that controlling nutrient enrichment from cropland runoff could significantly improve conditions of low dissolved oxygen during periods of high runoff (Crutchfield, 1987).

The problem of modeling estuarine water quality criteria in relation to environmental objectives or uses for management purposes is extremely complex and must be approached as a dynamic composite rather than a set of isolated or independent variables. A holistic modeling that accounts for the interaction of many factors is necessary in supporting and managing estuarine resources. Until such composite quantified management models are available, it will be difficult to assess the direct impacts on estuaries, and the response of estuaries and particularly their marine life, resulting from changes in single variables such as nitrate unless such changes represent large excess amounts. Such models are being developed but are not yet operationally available for any estuary. Progress appears to be most advanced for the Chesapeake Bay Interstate Regional Water Quality Project.

Despite the uncertainty arising from the lack of adequately tested operational models, the three Chesapeake Bay States have agreed to and are implementing measures toward the goal of reducing both nitrate and phosphate nutrient loadings by 40 percent. Nitrate loadings in the Chesapeake Bay are estimated to be about 10,000 tons per year, which is classified as "high." The nitrogen concentration, on the other hand is rated "medium," between 0.1 and 1.0 mg/L (NOAA/EPA Team on Near Coastal Waters, 1989).

New data and analyses from the first long-term study of water quality in the Chesapeake Bay indicate that the Bay may recover from excess nutrient levels in a matter of a few years, rather than several decades as previously thought, once the annual nutrient loading is reduced by the goal of 40 percent. This inference is based on the finding that nutrients settling in the sediment of the Bay do not accumulate as a permanent loading where algae would use the nitrogen buildup over and over again, keeping the Bay's waters in a continuous state of eutrophication. Early results from the long-term study indicate that up to 90 percent of the nitrogen entering the Bay is cycled out in the same year by bacterial denitrification, plants, fish, and the natural water flows (Davis, 1990 and Kemp, 1991).

However, in 1990, a Chesapeake Bay Nonpoint Source Evaluation Panel reported that their results left a question as to whether the present array of programs, implemented as designed at current funding levels, would be sufficient to achieve the goal of a 40-percent reduction in nutrients. Key improvements needed were more effective targeting to maximize nutrient pollution reduction per unit of program funding; a wider, more effective array of tools and techniques to reduce loadings, and a focus on nutrient management to achieve a net reduction of nitrogen and phosphorus entering the atmosphere, surface water, and ground water (EPA, 1991).

State Data and Assessments

State efforts to determine the extent and distribution of contamination of wells with nitrate and pesticides have expanded in recent years. Usually they provide more detailed data than found in national statistics. State surveys, however, are usually conducted in areas of greatest concern about the presence of nitrate or pesticides so they generally do not provide unbiased estimates of statewide or sub-area levels of contamination. Nevertheless, they do provide data about the dimension of local problems within States. The findings of studies and survey efforts of several States are selectively summarized below to characterize the range and nature of State efforts as well as the information they provide on nitrate occurrence around the country.

Nebraska. Nebraska in 1987 ranked third among the States in the use of nitrogen fertilizer. In 1990 it published a statewide assessment of nitrate in ground water. The results are summarized by well type in the table below.

Type of Well	Number of Wells	Level of Nitrate-N in mg/L <7.5	7.5<10.0	10.0<20.0	20.0<50.0	>50.0	Total
		Percent of Wells					
Domestic	3,927	76.3	.2	10.1	6.1	1.3	100
Irrigation	1,608	52.3	.0	18.3	12.0	.4	100
Public Supply	175	75.6	0.2	11.4	2.8	.0	100
Stock Use	81	74.1	6.2	7.4	8.6	3.7	100
Monitoring	35	60.5	12.2	27.3	- -	- -	100
Total	5,826	72.3	7.1	12.5	7.0	1.1	100

Note: The 5,826 groundwater samples were taken from wells that were stratified by county into one of three vulnerability classes on the basis of soil permeability and land use.

Nitrate-N concentration was less than 10 mg/L for nearly 80 percent of the sampled wells. Nitrate-N exceeded the 10 mg/L level in 20.6 percent of all the wells sampled. The corresponding percentages for irrigation and monitoring wells exceed this level, with 30.7 percent and 27.3 percent, respectively. In the case of irrigation wells the higher percentage may be due to the unweighted calculation of these percentages; areas of known or suspected contamination were sampled more heavily. Also some sampling sites were not selected randomly. For example, the monitoring wells generally were sited in areas of suspected nonpoint contamination. Thus, the percentages are not fully representative of the overall occurrence of nitrate contamination in Nebraska.

Except for stock wells the percentage of wells with more than 10 mg/L in each well type category decreases progressively with each 10-mg/L increase in nitrate-N level up to 50 mg/L. The greater frequency of domestic and stock wells with 50 mg/L or more nitrate-N than in irrigation wells is attributed to closer location of domestic and stock wells to farmstead point sources of nitrate contamination.

Nitrate-N above 50 mg/L occurs most frequently in eastern Nebraska, where poor well siting near barnyards and poor well construction in glacial till areas is not unusual and increases susceptibility to contamination. The location of a home, privy, barn, and feedlot 50 to 80 years ago on almost every 80 to 160 acre tract in eastern Nebraska and elsewhere in the Midwest may be a contributing factor. These conditions provided a source of nitrogen loading to the soil and ground water as well as the drinking water wells for many years (Power, 1991). Spalding and Exner reported that a 10-year resampling of 228 rural wells in eastern Nebraska showed no trend in nitrate concentration. The net change of nitrate-N was only plus 0.02 mg/L a year. They also reported that positive trends toward lower nitrate concentrations in many rural areas may be the direction of the future since "much of nitrate contamination is associated with a combination of poor well siting and construction" (Spalding and Exner, 1990).

Fifty-one percent of the elevated levels of nitrate concentration in the Nebraska assessment were in areas where ground water is highly vulnerable to contamination, areas where the depth to water is less than 50 feet and irrigated agricultural, particularly for corn production, is a major enterprise. Comparisons with earlier surveys show that nitrate concentration is increasing in irrigated corn-producing areas. In areas highly vulnerable to contamination both the concentration and areal extent of the contamination are rising (Exner and Spalding, 1990). For example, in Merrick County, which is 34 percent irrigated and has shallow ground water, nitrate-N in ground water rose from about 2.5 mg/L in the late 1940's to 7.5 mg/L in 1961 and to 11-12 mg/L in the 1970's (Keeney, 1986).

Arkansas. The Arkansas Cooperative Extension Service reported that a first round of sampling of rural wells in 10 pilot counties was completed in September 1989. The analysis for nitrate-N was done by the University of Arkansas Agricultural Diagnostic Laboratory. Only 3.2 percent of 1,232 wells sampled had nitrate readings exceeding the EPA health advisory level of 10 mg/L. An additional 11 percent had 3 to 10 mg/L. Nearly 86 percent had nitrate-N readings of less than 3 mg/L.

The incidence of high nitrate-N readings was greater in counties with high poultry and livestock production and lowest in predominantly cropproducing counties. These results were interpreted to "indicate that Arkansas does not have a bad problem of nitrates in ground water." Arkansas plans to confirm these initial results with a second sampling (Arkansas CES, 1990).

North Carolina. The North Carolina Agricultural Extension Service is conducting a groundwater education program that includes collecting 8,000 samples from wells in 30 counties and an evaluation of land and chemical use around the wells at time of sampling. First findings from some 3,000 samples in 11 counties are 64 samples, or about 3 percent, with nitrate-N concentrations greater than 10 mg/L. Median concentration is 0.7 mg/L. Incidence of nitrate-N in excess of 10 mg/L is greater in areas with more intensive agricultural land use. Up to 6 percent of the samples in such locations have more than 10 mg/L of nitrate-N (North Carolina AES, 1990).

Appalachia and Southeast. The concentration of farmland in the southeastern Atlantic Coastal Plain and the Piedmont Plateau of Virginia, the Carolinas, and Georgia is great, but there are few incidences of groundwater nitrate-N contamination. The Southeast is an area of extensive sandy soils that require heavy applications of fertilizer, receive high amounts of rainfall (50 inches), and are being rapidly developed for irrigation. However, much of the area is underlain by shallow retarding layers which tend to perch the recharge and divert its flow laterally to swamps whose vegetation uses the nutrients. Because many of the aquifers are confined or semiconfined in the Southeast, only very shallow or perched ground water appears to be subject to nitrate-N contamination. This was affirmed at plots on the Tifton Upland in Georgia. Nitrate leachates to shallow subsurface waters showed significant vertical stratification, as well as lateral concentration gradients in relation to distance from the center of the fertilized plots. Nitrate losses were attributed partially to denitrification and uptake by deep-rooted vegetation. A surfacewater study showed that nitrate-N levels in streams in the Georgia Coastal Plain had not increased in the past 50 years (Spalding and Exner, 1990).

Washington. The Washington Cooperative Extension Service recently reported on a number of local surveys that have been made to evaluate nitrate contamination in groundwater, but their information has not been aggregated (Washington CES, 1991). From 1986 to 1988 the USGS took 784 groundwater samples from 436 wells in Franklin and Benton Counties to check the distribution of nitrate in ground water. It included checking for sources of nitrate in service water irrigation systems at 54 locations, in subsurface drains in irrigated fields, and from soil and sediment core samples. The final report is still in preparation. Results are not otherwise available.

In the fall of 1987 and spring of 1988 samples were taken by USGS from 250 wells in southern King County to test for nitrate and pesticides but "nothing much was found in the way of nitrate." Similar tests were made by USGS in 1989 in northern Thurston County, where 360 wells were sampled in McAllister Spring in Olympia, Washington. A positive correlation was found between density of nitrate and density of residential development. A survey done in parts of Whatcom County in 1973 revealed "large samples of nitrate in 5 percent of the ground water sampled." A follow-up survey was being made in the fall of 1990 to pin down the sources of nitrate in ground water. The survey will take samples from 100 to 125 wells to test for nitrate, chloride, and iron. In 1987, 81 wells were sampled for nitrate-N in the agricultural areas of Whatcom, Franklin and Yakima Counties that had shallow ground water and other conditions that made them vulnerable to contamination from agriculutral chemicals. Nitrate-N was detected in 61 of the 81 wells at concentrations of 0.01 to 24.4 mg/L. The 10-mg/L level was exceeded in 18 wells: 7 in the Whatcom County study area and 11 in Franklin County. The study reported that observed nitrate concentrations in the Whatcom and Franklin County study areas were substantially higher than reported historical concentrations. Agricultural practices were illustrated as the likely source (Erickson and Norton, 1990).

California. California is a heavy user of nitrogen fertilizer and irrigates more acres than any other State. This combination has resulted in large areas of nitrate contamination of ground water. A summary of several studies reported that beneath several irrigated California valleys the nitrate-N in ground water ranged from 40 to 60 mg/L (Keeney, 1986).

Pennsylvania. Groundwater quality data were collected from all regions of Pennsylvania from 1974 to 1983 as a public service by the Soil and Forage Testing Laboratory, The Pennsylvania State University. The samples, from private wells, were largely provided by rural owners who perceived a water quality problem. Samples were analyzed for up to 15 contaminants including nitrate (Sharpe et al., 1985).

Statewide, 14.1 percent of 380 wells and 81 springs tested had mean levels of nitrate-N exceeding 10 mg/L. Medians were substantially lower than means, indicating the influence of few wells with relatively high nitrate concentrations on mean levels. The data are summarized below by well depth or spring source.

Source	Number of Wells	Nitrate-N Level in mg/L	
		Median	Mean
Wells less than 80 feet	108	1.9	4.6
Wells deeper than 80 feet	272	1.6	4.2
Springs	81	1.8	3.1

The differences in medians and means among these sources were not statistically significant. The percentage of tests exceeding the health standard is biased upward since the samples were submitted because a water quality problem was suspected. USGS data as of 1984 reported that 5.9 percent of individual sampled wells analyzed in Pennsylvania had nitrate-N concentrations exceeding the 10-mg/L health standard (Madison and Brunett, 1985).
A regional comparison of the same data showed that the highest levels of nitrate concentration occurred in the southeastern and southcentral parts of the State, where agriculture is much more intensive, especially dairying with the accompanying problem of manure disposal. Direct recharge of the groundwater reservoir via surface runoff to openings (sink holes) in highly weathered carbonate bedrock is also prevalent. Regional mean and median levels were well below the EPA health advisory level of 10 mg/L for nitrate-N as shown below:

Nitrate-N Level in mg/L, Pennsylvania, 1984		
Region	Median	Mean
Northwest	0.1	0.6
Southwest	0.3	— 1/
Northcentral	0.3	2.0
Northcentral	2.0	4.6
Southeast	4.1	6.4
Northeast	1.3	4.1

1/ Not reported.

Minnesota. Between July 1955 and June 1987 a cooperative Minnesota Department of Health (MDH) and Department of Agriculture (MDA) survey was undertaken to develop baseline data on nitrate and pesticide contamination in ground water. Over 700 wells were tested including monitoring wells near farm fields, and public and private drinking water wells. Wells were generally chosen in places where hydrogeology made the ground water especially vulnerable to contamination (Minnesota WRC, 1988).

MDH and MDA found that 42 percent of 199 private drinking water wells and 7.1 percent of 395 public water supply wells had nitrate-N in excess of the 10 mg/L standard. Data from two counties showed that nitrate contamination was increasing in deeper aquifers.

The earliest investigations of nitrate in wells were made in the late 1940's for wells thought to be involved in cases of methemoglobinemia. All of the wells investigated at that time had nitrate levels in excess of the current drinking water standard, and not one of the investigated wells was both constructed and located satisfactorily by MDH standards. Problems included locations too close to barnyards and cesspools. A comparison of the nitrate content of school well-water and similarly constructed nearby farm wells showed lower nitrate in the schools wells, further highlighting the role of location. Using data collected between 1978 and 1986 the Minnesota Pollution Control Agency compared nitrate levels in surficial sand aquifers in limited, moderate, and intensive agricultural counties. Analysis showed elevated levels of nitrate in the moderate and intensive farming areas in comparison to the levels found in the limited farming areas.

MDA compiled data on nitrogen fertilizer use from sales data showing that its use increased from 50,000 tons in 1960 to 850,000 tons in 1985. Much of the increase is attributed in part to a 31-percent increase in cropland in the same period. Most of the increase, however, was due to increased emphasis on higher yielding, and therefore more nutrient-demanding, crop varieties. USGS studies of nitrate in surficial sand aquifers produced the following findings: (1) nitrate plus nitrite- nitrogen levels increased in local agricultural areas between the mid- to late 1960's and 1978 and 1979; (2) high concentrations of agrichemicals were found following major recharge events, and (3) levels of nitrate increased significantly down-gradient from major agricultural and irrigation areas. In other studies USGS found nitrate-N levels higher in irrigated and residential areas as compared to nonirrigated cultivated and undeveloped areas.

Ohio. A statewide survey of nitrate in private wells was completed between 1986 and 1988 (Baker et al., 1989). The sample was based on voluntary responses of well owners to well-testing programs offered by local organizations in cooperation with the Heidelberg College Water Quality Laboratory, which analyzed the samples. A total of 16,166 samples from 76 counties were received and analyzed. Only 12 counties did not participate. Some 59 counties submitted 100 or more samples. The nitrate findings are summarized below, separately for drinking water and stock water uses. The total of all wells indicates a small overlap in these uses.

The survey results are believed to be representative for Ohio on the basis of the size and distribution of the sample, even though the sample was not randomly selected. Results were similar to 339 well samples analyzed by USGS of which 2.6 percent had nitrate-N in excess of 10 mg/L and 61.7 percent had levels less than 0.2 mg/L, a pattern very similar to the Ohio statewide nitrate survey results (Madison and Brunett, 1985). The findings also point out that nitrate levels in wells do not represent aquifer or groundwater conditions since contamination in private wells can result from faulty well construction or maintenance that permits contaminated surface water to enter the well directly. The Ohio survey did not collect data to determine sources of contamination where it was found.

About 2 million Ohio residents rely on private wells for their drinking water. The 2.7 percent of the drinking water wells with nitrate exceeding the 10 mg/L indicates about 54,000 residents are using water which, without treatment, exceeds the EPA health standard for nitrate. The relatively low incidence of nitrate in excess of EPA standard is likely related to the near absence of counties with a high ranking for vulnerability to groundwater contamination. Only two counties in this study ranked in the high vulnerability range based on national scales of vulnerability. Nitrate-N contamination beyond 10 mg/L is quite dispersed, both among counties and within those counties where it occurs. It does not appear to be very well correlated with areas of intense agriculture. Only three agricultural counties had samples with nitrate-N over 10 mg/L in as many as 10 or 11 percent of the sampled wells. There were 13 agricultural counties with no well samples exceeding the 10 mg/L standard. The highest mean level of nitrate-N calculated among the 76 county samples was 3.07 mg/L in Highland County.

Ohio Statewide Survey of Nitrate in Private Wells, 1986-88

Type of Well	Number of Wells	Nitrate-N Concentration in mg/L <0.3	0.3<3.0	3.0<10.0	>10.0	Total
		Percent of Wells				
Drinking Water	14,478	69.9	17.4	10.0	2.7	100
Stock Use	3,890	65.6	17.1	12.7	4.7	100
All	16,166	68.4	18.3	10.4	2.9	100

Proximity to septic tanks, cropland, and feed lots, as reported by well owner participants, did not appear to strongly influence the incidence of nitrate-N concentrations in the private water systems. The influence of well casings, whether or not they extended above grade, was likewise slight. Well age and depth seemed to have more influence than proximity to a potential nitrogen source. For example, 14 percent of the wells built before 1900 had nitrate levels exceeding the EPA health standard compared to 3, 2, and 1 percent, respectively, for wells constructed during 1900-44, 1950-70, and after 1970. Among some 2,400 wells less than 50 feet deep and among 546 springs, only 7 percent of their number in each case had levels greater than 10 mg/L. For wells 50 to 100 feet deep the percentage was 1.7 percent and for wells over 100 feet deep the percentage was 0.9 percent.

Iowa. A statewide Rural Well-Water Survey was undertaken between April 1988 and June 1989 to provide statistically valid estimates of the quality of private well drinking water for the State as a whole and six subareas. It addressed two questions: (1) What proportion of private rural wells in Iowa are affected by various environmental contaminants including nitrate? and (2) What proportion of Iowa's rural residents are using well water containing such contaminants? The survey used a systematic sampling framework to sample 686 rural private farm and nonfarm wells in every county in the State. The county samples were related to population size.

The central finding of the survey for nitrate is that the drinking water in an estimated 18.3 percent of the rural private drinking-water wells in Iowa are contaminated in excess of the 10 mg/L health advisory standard. The contamination beyond the health advisory level varies considerably by State subareas: from less than 6 percent of the wells sampled in north-central Iowa to more than 38 percent in northwestern Iowa. On a statewide basis 35.1 percent of the wells less than 50 feet deep had elevated nitrate-N in excess of the health advisory level, as compared to 12.8 percent for wells deeper than 50 feet. The typical natural background concentration of nitrate-N in Iowa's groundwater aquifers is reported to be less than 2 mg/L, and often less than 1 mg/L. Higher levels in Iowa indicate a degree of pollution by fertilizer, manure, septic tank wastes, sewage sludge, or other sources.

Based on Iowa's rural population in 1980, about 130,000 residents or 17.9 percent of the rural population are using drinking water from private wells that contain excessive concentrations of nitrate.

The estimates from this Iowa survey for proportion of wells with nitrate-N exceeding 10 mg/L are much higher than those developed from USGS data in 1984. The USGS estimate in 1984 was 5.0 percent (Madison and Brunett, 1985). However, the USGS sampling methods take precautions to ensure that the samples tested represent the waters of the aquifers rather than the standing water in the well that is usually pumped for drinking water purposes. The Iowa survey sampled the latter. Thus, the Iowa survey may reflect substantial well contamination directly from surface sources on the farmsteads rather than general aquifer contamination.

The Iowa survey report advises that 1988 and 1989 were the two driest consecutive years in Iowa's recorded history. The statewide precipitation was more than 18 inches below normal. The survey summaries report that "This undoubtedly has influenced the results. Other longer term monitoring suggests that the concentrations of nitrate were lower in this period of the survey than in prior years." Readers of the survey summaries interpreting these results are advised to "keep in mind, the pronounced drought conditions" mentioned above (University of Iowa et al., undated).

Q1. APPENDIX
TABLE 1. Median Level of Nitrate-N in Water Samples of Principal Aquifiers By State[1/]

State	Number of Principal Aquifers Tested					
	Total [2/]	Median Nitrate Level in mg/L				
		<.1	.1<1.0	l.0<3.0	3.0<10.0	10.0 or>
Alaska	9	5	4	0	0	0
Arizona	13	0	3	7	3	0
Arkansas	6	0	6	0	0	0
California	8	0	5	1	2	0
Colorado	15(1)	4	6	1	4	0
Connecticut	4	0	3	1	0	0
Delaware	9	2	4	2	1	0
Florida	5	2	3	0	0	0
Georgia	6	6	0	0	0	0
Hawaii	6	1	2	2	1	0
Idaho	6	0	5	1	0	0
Illinois	2(1)	0	2	0	0	0
Indiana	5	0	4	1	0	0
Iowa	5	4	1	0	0	0
Kansas	5(2)	0	2	0	3	0
Kentucky	6	0	5	1	0	0
Louisiana	(8)	No samples reported for nitrate				
Maine	3(1)	0	3	0	0	0
Maryland	10	3	3	3	1	0
Massachusetts	(4)	No samples reported for nitrate				
Michigan	5	5	0	0	0	0
Minnesota	13	5	6	1	0	1
Mississippi	(14)	No samples reported for nitrate				
Missouri	6	6	0	0	0	0
Montana	7(1)	7	0	0	0	0
Nebraska	8	1	3	3	1	0
Nevada	13	1	11	1	0	0
New Hampshire	2	0	2	0	0	0
New Jersey	8(1)	3	3	2	0	0
New Mexico	11(3)	0	2	8	1	0
New York	10(2)	1	5	3	1	0
North Carolina	5	2	3	0	0	0
North Dakota	6(1)	1	5	0	0	0
Ohio	4	2	2	0	0	0
Oklahoma	(9)	No samples reported for nitrate				
Oregon	3	0	3	0	0	0
Pennsylvania	4	0	2	1	1	0
Rhode Island	8	7	1	0	0	0
South Carolina	6	5	1	0	0	0
South Dakota	5(1)	2	3	0	0	0
Tennessee	4(4)	2	2	0	0	0
Texas	7	0	2	0	5	0
Utah	12(1)	0	4	6	2	0
Vermont	3	0	3	0	0	0
Virginia	9	6	2	0	1	0
Washington	9	5	4	0	0	0
West Virginia	9	8	1	0	0	0
Wisconsin	5	5	0	0	0	0
Wyoming	4	0	4	0	0	0
TOT. AQUIFERS	316(54)	102	140	46	27	1
NO. OF STATES	46(4)[3/]	27	40	19	11	1
% AQUIFERS	100.0	32.3	44.3	14.6	8.5	0.3

[1/]A principal aquifer refers to an aquifer contained wholly within a State or that segment of a multi-state aquifer that falls within the boundary of an individual State.
[2/]Number in parentheses indicates aquifers not tested for nitrogen.
[3/](4) refers to the 4 States for which data on tests for nitrate-N levels in principal aquifers were not reported by USGS.
Source: USGS National Water Summary, 1986

Q1. APPENDIX
TABLE 2. The 90th Percentile Nitrate-N Level In Water Samples of Principal Aquifers By State

	90th % Nitrate Level in mg/L					No. of Samples Tested		
State	<.1	.1<1.0	1.0<3.0	3.0<10.0	>10.0	Median Samples	Range/ Aquifer	Total Samples
	No. of Aquifers Tested							
Alabama	0	1	5	0	0	39	10- 95	239
Alaska	0	5	2	0	2	55	10- 534	1153
Arizona	0	0	7	3	3	44	13- 450	1232
Arkansas	0	4	0	2	0	161	46-2007	2746
California	0	0	2	4	2	197	40- 482	1850
Colorado	0	3	4	5	3	35	9- 98	639
Connecticut	0	0	3	1	1	263	112- 478	1045
Delaware	2	2	2	2	1	17	9- 84	196
Florida	1	1	3	0	0	581	13- 171	369
Georgia	0	2	4	0	0	121	10- 283	784
Hawaii	0	1	5	0	0	27	9- 73	154
Idaho	0	1	3	2	0	228	27- 652	167
Illinois	0	0	2	0	0	266	74- 457	531
Indiana	0	0	2	2	1	47	21- 186	751
Iowa	0	1	1	3	0	91	50- 676	1051
Kansas	0	0	0	2	3	32	25- 99	233
Kentucky	0	0	1	5	0	406	238- 802	2822
Louisiana			No samples reported for Nitrate					
Maine	0	0	2	1	0	31	19- 74	124
Maryland	0	3	3	1	3	35	15- 167	592
Massachusetts			No samples reported for Nitrate					
Michigan	2	3	0	0	0	14	4- 82	123
Minnesota	0	6	3	2	2	16	2-1603	1910
Mississippi			No samples reported for Nitrate					
Missouri	6	0	0	0	0	60	20- 928	1225
Montana	0	0	4	2	1	102	7- 769	1303
Nebraska	1	0	1	4	2	19	1-1236	1910
Nevada	1	3	6	2	1	188	4- 286	955
New Hampshire	0	0	2	0	0	28	16- 41	57
New Jersey	2	1	3	2	0	49	10- 646	1081
New Mexico	0	1	8	1	1	65	17- 456	1137
New York		1	4	5	0	89	5- 248	990
North Carolina	0	2	3	0	0	142	19- 433	855
North Dakota	0	2	4	0	0	17	5- 941	1074
Ohio	0	2	1	1	0	33	32- 48	165
Oklahoma			No samples reported for Nitrate					
Oregon	0	1	2	0	0	96	77- 111	284
Pennsylvania	0	0	1	1	2	237	144- 300	818
Rhode Island	0	2	5	1	0	50	16- 105	399
South Carolina	0	2	4	0	0	80	24- 167	511
South Dakota	0	2	1	0	2	64	7- 143	346
Tennessee	2	1	1	0	0	26	12- 387	104
Texas	0	0	0	1	6	2837	596-4604	17299
Utah	0	0	5	5	3	22	10- 105	523
Vermont	0	1	2	0	0	49	44- 174	264
Virginia	0	4	3	1	1	32	15- 209	666
Washington	0	1	5	2	1	253	14- 511	2172
West Virginia	0	4	2	2	1	59	12- 387	1069
Wisconsin	0	2	1	2	0	317	14- 946	2020
Wyoming	0	1	2	1	0	102	87- 335	628
TOTAL	17	66	124	68	41	-	-	58074
PERCENT	5.4	20.9	39.4	21.5	13.0	-	-	-

Source: USGS National Water Summary, 1986

Q1. APPENDIX
TABLE 3. Summary of the Maximum Measured Nitrate-N in Ground Water by State.

State	Number of wells sampled	Percentage of wells for which maximum nitrate-N concentration fell within indicated mg/L range			
		0-0.2	0.21-3.0	3.1-10.0	More than 10.0
Alabama	244	47.1	45.5	7.4	0.0
Alaska	1,305	60.9	33.9	2.8	2.4
Arizona	4,164	12.1	49.7	24.4	13.9
Arkansas	2,436	49.1	38.5	8.5	3.9
California	2,732	21.9	45.4	22.5	10.1
Colorado	5,492	33.8	43.3	17.2	5.7
Connecticut	348	33.6	49.7	14.4	2.3
Delaware	165	34.5	30.9	25.5	9.1
Florida	3,140	71.5	24.2	2.3	2.0
Georgia	1,137	66.7	28.5	4.3	.5
Hawaii	164	15.9	75.0	9.1	.0
Idaho	1,806	33.3	52.0	12.9	1.7
Illinois	359	56.0	30.1	5.6	8.4
Indiana	650	55.4	33.4	9.7	1.4
Iowa	4,088	44.9	36.7	13.4	5.0
Kansas	1,140	17.0	28.8	34.2	20.0
Kentucky	3,227	36.5	46.2	13.0	4.2
Louisiana	3,177	78.3	19.4	1.8	.6
Maine	147	50.3	35.4	12.2	2.0
Maryland	1,521	40.9	30.4	22.0	6.8
Massachusetts	414	42.3	52.2	4.3	1.2
Michigan	1,108	79.1	17.1	2.8	1.1
Minnesota	1,655	39.1	40.7	10.9	9.3
Mississippi	1,701	76.5	21.7	1.6	.2
Missouri	2,165	64.2	27.2	6.6	2.1
Montana	2,821	43.4	45.1	7.7	3.8
Nebraska	2,326	18.0	49.3	23.4	9.3
Nevada	465	46.2	45.4	7.5	.9
New Hampshire	69	66.7	29.0	2.9	1.4
New Jersey	1,385	63.0	25.6	10.0	1.4
New Mexico	4,685	38.4	48.9	9.8	2.9
New York	2,491	28.9	30.8	29.3	11.0
North Carolina	908	72.1	22.0	5.1	.8
North Dakota	7,387	22.4	68.5	4.4	4.6
Ohio	339	61.7	29.8	5.9	2.6
Oklahoma	1,724	23.0	41.2	24.1	1.2
Oregon	685	57.1	36.4	5.4	1.2
Pennsylvania	4,326	31.1	38.7	24.4	5.9
Puerto Rico	79	16.5	48.1	32.9	2.5
Rhode Island	171	17.0	38.0	8.8	36.3
South Carolina	557	69.3	26.6	3.4	.7
South Dakota	1,996	49.2	35.9	8.2	6.7
Tennessee	109	65.1	29.4	4.6	.9
Texas	36,196	<—76.5—>		14.1	9.4
Utah	3,301	39.1	50.4	8.4	2.0
Vermont	73	52.1	41.1	5.5	1.4
Virginia	762	70.7	25.9	2.6	.8
Washington	1,158	38.3	38.9	18.6	4.3
West Virginia	954	68.6	25.9	5.0	.5
Wisconsin	2,727	40.1	41.3	15.1	3.6
Wyoming	1,477	47.9	40.7	7.6	3.8
NO. OF WELLS	123,656	99,419		16,322	7,914
PERCENTAGE	100.0	<—80.4—>		13.2	6.4

[1/] Percentages may not add to 100 percent for each State due to rounding

Source: Madison and Burnett, 1985. Data from samples collected and analyzed by the USGS and Texas Department of Natural Resources over 25 years.

QUESTION 2. What are the Seasonal and Longer Term Patterns and the Influences of Other Factors Associated with Nitrate Concentrations in Wells?

Executive Summary

The available data on nitrate contamination in ground water beyond the 10 mg/L standard, attributable to either point or nonpoint sources, indicate that it is highly locale-specific. Predicting specific nitrate concentrations, however, is very difficult for two reasons. The variance in sample nitrate measurements within and between wells in the same locale and within years and between years or seasons is very large. Many interacting factors that are difficult to quantify are involved in explaining that variance. These factors extend beyond those relating to source. They include climatic and weather variation, the various hydrologic properties of the cultivated soil, the underlying vadose zone, and the shallow aquifers which can influence the amount, location, and timing of nitrate accumulation in ground water and the amount and intensity of irrigation and fertilization. States are recognizing the difficulty of predicting nitrate concentrations and are encouraging well owners to routinely test their well waters. Many States are conducting systematic surveys for nitrate contamination.

For the foregoing reasons it is also difficult to determine long-term trends in nitrate concentration in ground water with statistical reliability. Only a few studies on long-term trends are available. A statewide analysis of nitrate-N concentration in ground water in Nebraska, based on irrigation well samples taken in the early 1960's and 1970's, found that nitrate-N increased about 25 percent on a statewide average basis over that 10-year period. During this 10-year period the use of fertilizer N increased four times and the Nebraska average rate of use on corn exceeded that of all other States. That study projected it would take over 100 years to increase the average nitrate-N concentration in Nebraska's ground waters to the 10 mg/L health advisory level. However, the study also found there were local areas where nitrate-N levels exceeded the statewide average and other areas where the rate of increase was substantially greater than the statewide average increase.

The USGS studied trends in nitrate concentration in ground water in six separate Nebraska study areas representing diverse climatic, hydrologic, soil, and farming conditions for a longer and more recent period, 1960 to 1983. It found a statistically significant trend in only one of the areas which showed an average rate of increase of 0.12 mg/L per year from a 1960 level of 1.0 mg/L. A few other studies in other States show similar locale-specific increases in nitrate-N levels in ground water, and a few indicate an expansion of the areal extent of nitrate contamination.

Contaminated pockets of high nitrate concentration in aquifers are most frequently associated with unconfined shallow aquifers or karst settings with overlying shallow, sandy, or gravelly soils. There are locations in at least 14 States with high agricultural production where nitrate contamination has been associated with the application of nitrogen fertilizers. In some cases it has been demonstrated that the leaching of nitrate is accelerated by irrigation, as in some permeable Nebraska soils.

Denitrification reduces nitrate levels in soils and has been identified as a basic factor contributing to the generally low levels of nitrate found in the ground waters of the Southeastern United States. It is also considered to be a cause of reduced nitrate levels in the ground waters of the eastern Cornbelt. Water table management to increase denitrification is now being considered and studied in several States as a best management practice to preclude or significantly reduce the leaching of nitrogen, particularly in the postharvest period before spring planting. Emerging research also indicates that on some soils, available best management practices that reduce the amount of nitrogen fertilizer application for optimum production are not sufficient to reduce the soil solution concentrate of nitrogen-N in the root zone after harvest to a level below 10 mg/L. This research indicates a need for improved practices in such situations and for new technology that can reduce the postharvest solution concentrate to an acceptable level.

Evidence from many Federal and State studies and surveys indicates that nitrate contamination of farmstead drinking water wells is often associated with farmstead sources such as barns, barnyards, septic systems, feedlots, silos, and buried organic material and with storage, handling, and mixing of fertilizers in the wellhead area. Wells most susceptible to contamination are more than 50-70 years old, of shallow depth (20 to 100 feet), located close to sources of nitrate contamination, or placed in a pump pit or low lying area; and have damaged or nonwatertight casings.

Seasonal Variation

The Ohio statewide survey of private wells included a subsample of 179 wells subject to bimonthly sampling and testing to identify extent of any seasonal pattern and individual well sample variability over a 12- month period from April 1988 to April 1989. The sample was selected to include a relatively greater number of wells whose survey findings showed higher nitrate findings. The sample covered 31 counties and attempted to include at least one well from each township in each of the 31 counties. The following tabulation shows distribution of the sample wells selected for the variability study relative to the early statewide survey findings, as well as final statewide survey results by nitrate-N concentration.

Nitrate-N Concentration in Wells	Early Statewide Findings Survey January 1988	Variability Study Sample	Final Statewide Survey Results
mg/L	Percent of Sample Wells		
0.0-<0.3	79.9	15	68.2
0.3-<3.0	10.0	9	18.5
3.0-<10.0	7.5	40	10.4
10.0 or >	2.5	36	2.9

Variation was analyzed for 152 wells whose owners had returned 47 of the 54 planned samples per well. Some owners had difficulty providing samples due to extreme drought in the summer of 1988, which dried up their wells. The mean nitrate-N level was expected to peak in the spring, either very early in the groundwater recharge period or later, immediately following fertilizer applications.

The mean level of nitrate-N concentration fluctuated in a downward pattern from about 7.0 mg/L on April 4, 1988, to a low of 5.5 mg/L on August 1, 1988. It stabilized at about 6.0 mg/L in the late summer and early fall. After November 7, 1988, it trended upward with a little fluctuation to more than 8.0 mg/L on April 3, 1989. The higher level of nitrate-N in April 1989 compared to April 1988 was not interpreted as a long-term trend but was attributed to the influence of weather conditions, particularly the drought. During the fall, winter, and spring many Ohio rivers had the highest nitrate-N concentrations ever observed in those seasons. These high concentrations were attributed to poor crop growth and associated low uptake of nitrogen by the planted crops due to the drought. The unexpected high mean level of nitrate in the wells in April 1989 was conditionally associated with these phenomena.

An analysis of the variability of nitrate-N concentration within individual wells failed to reveal any average consistent seasonal pattern. Concentrations fluctuated quite strongly in many wells. A few wells maintained relatively stable concentrations; however, most showed a dip in concentrations on the August 1 sampling date. For the 152-well variability subsample, a one-time finding of a concentration as low as 6 mg/L indicated a 50-percent chance of at least one reading above 10 mg/L during the year.

Conversely, some wells that exceeded 10 mg/L once during the year had median concentrations as low as 2 mg/L. Thus, it was concluded that given such variability, one sample is not sufficient to provide assurance that a well is persistently contaminated. (Note also that one sample is not sufficient to establish that a well is not contaminated.) It was also inferred that efforts to determine longer term trends in nitrate concentration may not be productive unless frequent sampling is carried out for several years (Baher et al., 1989).

Long-Term Trends in Nitrate Concentration

It is difficult to find comprehensive data on long-term trends in nitrate concentration. Some information is available from a few relatively localized studies.

Nebraska. A USGS study of the occurrence of nitrate-N in ground water for the years 1936 to 1983 in six areas of the High Plains aquifer in Nebraska (where it underlies 85 percent of the State) is one of the more comprehensive efforts to assess long-term trends (Chen and Druliner, 1988). The six Nebraska areas studied represented diverse hydrologic, climatic, soil, and agricultural use conditions and ranged from one to three counties in extent. In 1984, the number of registered irrigation wells varied from 886 in area 5, the most western, to 6,407 in area 1 in the Central Platte Valley. A total of 2,308 groundwater samples, collected between 1936 and 1983, were available for the six areas. However, sufficient data to test for the existence of trends in nitrate concentration at the 95-percent confidence level were available only for the area 1 including Buffalo and Hall Counties. Data were used for only 21 of the 24 years between 1960 and 1983 for which at least 10 well observations per year were available. The results showed that nitrate-N increased an average of 0.12 mg/L per year in this 24-year period. Actually, the median level of nitrate-N in Buffalo and Hall Counties remained relatively stable at about 1.0 mg/L through the 1960's with relatively small, more or less randomlike variations.

Significantly increased median levels first appeared in 1971 and thereafter ranged widely at about an average median level close to 4.0 mg/L. The average rate of increase of 0.12 mg/L per year for the 1960- 83 period of 24 years produces a trend level of 3.88 mg/L for 1983. The actual median for 1983, however, was only 2.4 mg/L. In 1984, it was slightly lower, 2.2 mg/L. The study further reported that nitrate-N concentrations may be increasing in the other five study areas but data were insufficient to detect such trends statistically at the 95-percent confidence level.

Successive area studies of nitrate concentrations in the Central Platte Valley in Nebraska between 1974 and 1984 have shown that the areal extent of nitrate-N concentration has enlarged and that the level of concentration in contaminated areas has increased. A primary source of contamination has been identified as leachate from commercial fertilizer. The study area has been classed as highly vulnerable and depth to water is less than 50 feet. Irrigated corn production and high fertilizer inputs have been identified as other contributing factors (Exner and Spalding, 1990).

Data for Merrick County, Nebraska, suggest that the upward trend detected in the Central Platte Valley may date back to the late 1940's. Merrick County was not sampled in the USGS study. It lies to the east and is one county removed from USGS study area 1. It likewise has shallow ground water and is heavily irrigated with 54 percent of its area under irrigation. Keeney reported that nitrate-N concentrations in Merrick County ground water rose from about 2.5 mg/L in the late 1940's to 7.5 mg/L in 1961 and to 11-12 mg/L in the 1970's (Keeney, 1986). The foregoing reported concentration of nitrate-N indicates about a 9-mg/L increase over about 27 years, or an arithmetic average of a 0.33 mg/L per year. This is a higher rate of increase than that calculated for USGS study area 1, but it is strictly not a comparable calculation due to differences in statistical method and time periods. The Merrick County trend increase of about 4.0 mg/L from 1961 to the 1970's is similar to that found for the USGS study area 1. However, the data for study area 1 show a peaking of nitrate-N sample measurements in the 1970's and a decline in the early 1980's.

Spalding and Exner reported the results of a 10-year resampling of 228 rural wells in eastern Nebraska where nitrate-N above 50 mg/L occurs most frequently and where poor well siting near barnyards and poor well construction in glacial till areas are not unusual and increase susceptibility to contamination. The resampling showed no trend in nitrate-N concentration. The net change was only plus 0.02 mg/L per year.

The study also hypothesized that positive trends toward lower nitrate concentrations in many rural areas may be the direction of the future since "much of nitrate contamination is associated with a combination of poor well siting and construction" (Spalding and Exner, 1990).

A comprehensive investigation was undertaken in Nebraska in 1971 and 1972 to determine the magnitude and sources of nutrient N in its ground and surface waters (Muir et al., 1973). Water samples were taken from irrigation wells at the midsummer peak pumping rates in 1971 and 1972. Additional water samples were taken from 32 sites on Nebraska's major streams on a quarterly basis in the same years. The study estimated that the nitrate-N concentration in ground water as determined from irrigation wells sampled in 1961-62 and 1971-72 increased about 25 percent on a statewide average basis. Well depths ranged from 10 to 100 meters with an approximate average static water level of 15 meters. During this 10-year period fertilizer N use increased four times so the Nebraska average rate of use on corn exceeded that of all other States. Based on the level of nitrate-N in 1961, the study projected it would take over 100 years to increase the average concentration of Nebraska gound waters to the 10 mg/L HAL. The study concluded on this basis that "the problem would not appear to be urgent."

However, it also reported there were local areas where current levels of nitrate-N were higher than the statewide mean and other areas where the rate of increase was substantially greater than the statewide average increase. Merrick County and several other counties were cited as cases in point. The study advised that means for reversing the latter trends "must be sought from now on rather than establishing permissible levels of further increase."

The mean concentration of nutrient N in Nebraska's streams (excluding the Missouri River) was found to be less than 1.0 mg/L over the three years 1970-72. The streams do not show a steady pattern of growth in the concentration of nutrient N or its total flow downstream within the State.

But there are wide fluctuations due to local intrusions and subsequent assimilation. Maxima usually occur in the spring and early fall when rainfall and runoff normally are the greatest. The average annual concentration of mineral N in rainfall in Nebraska is 2 mg/L, which is about triple that for streamflow. Thus, rapid cumulative runoff from heavy rainfall into streams can elevate the streamwater level of nutrient N to approach that of rainwater.

Correlation analyses of factors potentially associated with nutrient N in streams indicate that along with the stream flow rate, population density and livestock density are the dominant influences on nutrient N and sediment levels in streams. The percentage of land devoted to legume cultivation also has a bearing, but less than the population factor. Irrigation does not seem to influence nutrient N in streams, apparently because most of the irrigation occurs in the drier locations west of the area of high population and maximum rainfall and streamflow.

Other Studies. Patterns such as reported for Nebraska may be occurring elsewhere. For example, McDonald and Splinter analyzed data from 4,597 water samples taken from municipal water supplies from all parts of Iowa. They showed that nitrate levels in ground water from wells less than 100 feet deep increased slowly, but steadily between 1952 and 1979 where total fertilizer use and the application per acre were increasing rapidly (McDonald and Splinter, 1982).

Long-term monitoring of ground water for nitrate trends is available for Karst topography in the locale of the confluence of Iowa, Wisconsin, and the Minnesota border. This area's numerous sinkholes intercept much of the surface runoff and therefore are sites for direct groundwater recharge and a direct route for groundwater nitrate contamination. The Big Springs Basin in northeastern Iowa is managed almost entirely for mixed agricultural production, and Big Springs discharges all of the ground water originating in the Basin. The nitrate-N concentration in the Big Springs Basin increased from 5 mg/L in 1958 to 15 mg/L in 1982. These data

suggest an average rate of nitrate-N concentration of 0.4 mg/L per year. A farm survey of nitrogen use found that nitrogen application rates were not being adjusted for alfalfa or manure sources of nitrogen. In 1984, about 90 kilograms per hectare more fertilizer nitrogen was applied than was needed. This excess was about equal to the nitrogen exported in Big Springs (Keeney, 1986).

For 12 wells in surficial sand-plain aquifers in west-central Minnesota for which historical data were available, the mean nitrite plus nitrate concentrations in a 1982-84 study period were greater than mean concentrations during earlier studies conducted by the USGS between 1965 and 1978. However, the increase in mean concentration in the 1982-84 period over previous record levels of nitrate-N was not as great as the seasonal fluctuations observed in the 1982-84 period.

Thus, the short-term seasonal fluctuations were greater than the apparent historical increase in nitrate concentration (Anderson, no date). Nevertheless, the earlier USGS studies found that nitrite and nitrate levels increased in the superficial sand-plain aquifers in local agricultural areas between the mid- to late 1960's and 1979 (Minnesota Water Resources Committee, 1988).

Nitrate Concentration by Well Depth

USGS compared maximum nitrate-N concentrations by well depth for nearly 124,000 wells (Madison and Brunett, 1985). As mentioned previously, this analysis used the maximum nitrate-N concentration where a well had more than one sample measurement. Taken together with the higher density of USGS sampling of wells for nitrate-N in locations where there was a known problem of nitrate in water, this method lends an upward bias to calculated percentages of wells in the highest nitrate-N category, over 10 mg/L, and a downward bias for percentages in the lowest nitrate-N category. The findings are summarized in the following tabulation:

Distribution of Nitrate-N by Well Depth for Over 123,000 Wells in the United States [1/]

Maximum Nitrate-N per Well mg/L	Well Depth in Feet < 100	100-200	201-300	>300	Number of Wells
	Percent of Wells				
0.0-<3.0	32	21	13	34	99,419
3.0-10.0	51	22	11	16	16,322
>10.0	67	17	6	10	7,914
Number of Wells	45,441	25,814	15,195	37,205	123,655

[1/] Includes about 87,000 wells in the USGS National Water-Data Storage and Retrieval System plus more than 36,000 wells from the Texas National Resources Information System for which Nitrate-N analyses are available (USGS data base has few data for Texas).

Two-thirds of the wells with more than 10 mg/L of nitrate-N were less than 100 feet deep. Over 50 percent of the wells with 3-10 mg/L of nitrate-N were less than 100 feet deep. Over two-thirds of the wells with less than 3 mg/L of nitrate-N were more than 100 feet deep. Because most nitrate sources are at the surface level one would expect shallow aquifers to be more susceptible to contamination than deeper ones.

Nitrate contamination of deeper ground water can occur where a hydraulic connection and a downward hydraulic gradient exist between shallow and deep aquifers and where sufficient time has elapsed for contaminants from shallow sources to migrate to deeper zones. Long-term increases in nitrate levels are a possibility where the deeper aquifers are recharged by nitrogen-rich water from shallow aquifers. But, the movement of drainage water through the unsaturated zone of many soils can be very slow. Thus, the time for current inputs of nitrogen to reach the groundwater reservoir may be many years. Due to the slow movement of recharge waters, contamination of deeper wells could continue for many years where columns of nitrogen have been built up in the unsaturated soils, even though nitrogen use on the surface is reduced to efficient levels or even less.

Other Factors Influencing Occurrence of Excess Nitrate Contamination

Many factors influence the geographic distribution of nitrate-N contamination in excess of the EPA standard of 10 mg/L. Those factors include a wide variety of farmstead sources, the particular location of wells on the farmstead, hydrographic subarea, construction, condition and age of wells, climatic factors, soil characteristics, and agricultural practices, as well as the nitrogen-cycle processes of nitrification and denitrification. The individual influence of these factors is reasonably well known and understood. The complex interactions among these factors and heterogeneity of soil characteristics, climatic factors, and agricultural practices make it difficult to quantify any general conclusions about the regional potential for excess nitrate contamination or the regional impact of any single factor on such contamination. The best approach for determining where excess contamination exists or is a threat is through systematic surveys and direct sampling and analysis of well waters and ground water. The relatively low percentage of wells that are being found contaminated beyond the EPA health advisory level (HAL) is evidence in support of this approach. Individual States are increasingly adopting and applying this approach.

Iowa Analyses. An Iowa statewide Rural Well-Water Survey, carried out between April 1988 and June 1989, analyzed the frequency of wells with nitrate-N levels greater than 10mg/L, for wells less than 50 feet deep and for wells with unsafe levels of coliform bacteria for each of six State hydrologic subareas as follows (The University of Iowa and Iowa Department of Natural Resources, undated):

Hydrologic Subarea	Wells <50 Feet Deep	Wells with Unsafe Levels of of Coliform Bacteria	Wells with NO_3-N>10mg/L
	percent		
Northwest	52.8	67.3	38.2
Southwest	54.2	65.0	31.4
West-Central South	54.9	72.5	28.1
West-Central North	12.9	26.8	5.6
East-Central	12.5	34.3	11.6
Northeast	5.7	20.9	9.2

The Iowa data show a wide range of variation in the percentage of wells with excessive nitrate-N levels within the State. The data also show that the higher frequency of excessive well contamination is strongly associated with wells less than 50 feet deep and wells unsafely contaminated with coliform bacteria. The State subarea differences in excess contamination are highly significant statistically for both nitrate-N and coliform bacteria.

Coliform bacteria sources are animal wastes and septic system effluent or drainage. Since bacteria are filtered by soil and rarely infiltrate more than a few centimeters into the soil profile, coliform bacteria must enter wells primarily from surface runoff. Runoff from farmstead livestock manure sources or septic system drainage will contain extremely high numbers of bacteria if the manure has not been incorporated into the soil or the bacteria have not been stressed (USDA, 1983). Thus, it is likely that much of the nitrogen-N contamination in wells also contaminated with coliform bacteria originates from livestock manure sources or septic system effluents and enters through either surface runoff or leaching through the soil, or through both routes.

Nebraska Analyses. A 1980 survey for nitrate in Nebraska's wells and ground water revealed that the Lincoln quadrangle in southeastern Nebraska had the most serious nitrogen contamination problem among six sampled quadrangles; 22 percent of the sampled wells showed more than 10 mg/L of nitrate-N. In one subarea of the Lincoln quadrangle, 23 out of 47 sampled wells exceeded the 10 mg/L nitrate-N standard and half of these had nitrate-N levels between 40 and 143 mg/L. As a result, a more closely spaced and better documented sampling and analysis was undertaken in 1981 and 1982 for 268 household and stock wells in the 1,100-square-mile agricultural area (4 counties) of this quadrangle. Most of the farms were cash grain/livestock operations averaging 44 and 60 head, respectively, of cattle and hogs. The vast majority of farms had at least a few head of livestock. Nitrogen fertilizer use, usually as liquid, was low (Exner and Spalding, 1985).

The follow-up survey found that 71 percent of the 268 samples had nitrate-N in excess of 10 mg/L and/or total coliform densities greater than 1/100 ml. Using N-15 methods of analysis for 115 samples with more than 8.5 mg/L of nitrate-N, it was determined that human and animal wastes were the primary source of nitrate contamination. That suggested that fertilizers or mineralized soil nitrate were not major sources of groundwater nitrate contamination in the Lincoln quadrangle. The predominant source of nitrate contamination was attributed to manure in feedlots, barnyards, and corrals that were either abandoned or used only intermittently, such that the manure pack was subject to drying, cracking, nitrification, and leaching when feeding was discontinued in the summer months.

Nitrate is less likely to leach to the deep soil of feedlots that are continuously stocked and have undisturbed and continuously accumulating manure pack where hoof compaction and urine excretion keep the surface sealed, damp, and reducing. Nitrification is unlikely under such conditions. Septic system effluents appeared to be a much less frequent source of nitrate contamination than animal waste sources. A high incidence of elevated nitrate was found at 17 sites with wells located within 100 feet of a septic system. In general, the lowest incidence of nitrate contamination was found at wells where there was neither an observed nor a reported source of nitrogen. Only 18 out of 128 such wells had nitrate-N in excess of 10 mg/L. In those cases, the study reported that it was likely that an N source had been present at one time; though its vestiges were obliterated, it was likely still contributing nitrate to well contamination. The rates of contamination by source were as follows:

Sources and Levels of Well Contamination With Nitrate, Lincoln Quadrangle, Nebraska, 1981-82

Source of N	Wells	Mean Level of N03-N	Wells w/ $N0_3$-N > 10 mg/L
	Number	mg/L	Percent
None	128	6.5	14
Septic System	17	24.0	64
Intermittently Used Barnyard	58	16.0	40
Abandoned Barnyard	65	30.0	71

The Lincoln quadrangle study also evaluated the influence of well construction on nitrate and coliform bacteria contamination. Only 27 of the 268 wells (10 percent) met Nebraska's criteria for private well construction. Nitrate-N exceeded the 10-mg/L level in only one of these wells (4 percent). However, 8 of these wells (30 percent) contained a total coliform (TC) density of 1/100 milliliters or more.

Samples from dug or augered wells with open-jointed casings exceeded the nitrate-N and TC standards more frequently, 47 percent and 80 percent of the time, respectively. Most of these wells were at least 60 years old. In general, the proximity of a well to a source of nitrogen, the placement of a well in the pump pit or low lying area, or the use of nonwatertight casings made such wells the prime candidates for contamination.

In 1984 the USGS comprehensively analyzed nitrogen contamination of ground water for 82 well sites in the six study areas in Nebraska previously described under the section on Long Term Trends in Nitrate Concentration (Chen and Druliner, 1988). During the 1984 irrigation season, 82 wells distributed among the six study areas were sampled for nitrate-N concentration. The results are summarized in table 5.

Table 5. Occurrence of Nitrate-N in Six Study Areas of the High Plains Aquifer, Nebraska, 1984

	Study Area						
Observation	1	2	3	4	5	6	Total
No. of wells [1/]	15	9	15	10	11	22	82
	Concentration in mg/L						
Median	2.2	7.1	2.3	5.8	3.3	3.6	3.7
Mean	13.1	6.4	2.4	8.2	4.6	9.1	7.6
Range: lowest	.1	.2	1.0	2.5	2.4	.2	.1
highest	45.0	14.0	4.0	28.5	13.0	39.0	45.0

[1/] Note: The sampled wells were free from any obvious point-source contamination and were chosen to represent a diversity of hydrologic conditions.

The table 5 nitrate-N data for the six study areas reveal a very large variance in nitrate-N concentrations for different locations of the High Plains aquifer. The median levels range from 2.2 to 7.1 mg/L with a weighted average median of 3.7 mg/L. The arithmetic mean levels of nitrate-N vary over twice as large a range, from 2.4 mg/L to 13.1 mg/L. This wider variation of means at the upper end of the nitrate-N concentration scale and generally lower medians suggests a skewness of a relatively few nitrate tests toward higher concentrations. That skewness is reflected in table 5 by the lowest and highest limits in the range of nitrate-N concentration test results for the sampled wells within each study area. These data suggest a relatively small percentage of locations with nitrate concentrations above the HAL level despite the statistical evidence of an upward trend over a 23-year period in area 1 and the possibility of upward trends in other parts of Nebraska.

Nevertheless, the nitrate-N concentration in 18 of the 82 wells (22 percent) exceeded the 10 mg/L HAL. In area 1, the only study area showing a statistically significant upward trend in nitrate-N levels, 5 out of 15 sample wells had nitrate-N levels above 10 mg/L. In area 6, there were 8 out of 22, a slightly higher proportion. In area 3, none of the 15 wells exceeded the HAL. In the remaining areas 2, 4, and 5, only 5 out of their total of 30 wells exceeded the HAL.

Another test made on 81 of the 82 wells was a comparison of their nitrate-N levels where irrigation well density was less than two per square mile and where the density was 2 or more per square mile. Nitrogen-N levels were significantly greater at the 95-percent confidence level beneath the more intensively irrigated areas; 55 wells had a median nitrate-N level of 4.11 mg/L. In the less intensively irrigated area, 26 wells had a median nitrate-N level of 2.3 mg/L.

The nitrate-N data from these same 82 wells were used in multiple- regression analyses to test the adequacy of nine variables for predicting nitrate-N concentrations in ground water. Three variables (well depth, irrigation well density, and nitrogen fertilizer use) explained 51 percent of the variation in nitrate concentration. Other variables tested were: hydraulic gradient, hydraulic conductivity, specific discharge, depth to water, annual precipitation, and soil permeability. These six variables explained less than two percent of the remaining 49 percent of the variation. The physical interpretation of these statistical results indicates that nitrate concentration is greater in ground water that is near the surface and beneath those fields more heavily irrigated and fertilized with nitrogen.

Kansas Analyses. As part of a comprehensive study of water quality from farmstead wells conducted by Kansas State University and the Kansas Department of Health and Environment's Bureau of Water Protection, information was collected on a selected sample of 150 farmstead wells. Data were used to determine the well characteristics and surrounding conditions associated with the level of well contamination with nitrate (Koelliker et al., 1988). The selected wells had the following distribution in relation to nitrate-N levels as determined in the more comprehensive survey.

Nitrate-N Level	Wells With Lower Nitrate-N Level
mg/L	Cumulative Percent
1	23
4 1/	41
10	67
20	83
40	95
140	100

[1/] For wells in Kansas 4 mg/L is considered the background nitrate-N level.

In general, this study concluded that wells were most likely to have nitrate-N levels above 10 mg/L or above 20 mg/L if they were:

— more than 70 years old;
— within 100 feet of a source of potential organic contamination (septic tanks, feedlots including confinement buildings or abandoned feedlots, or silos);
— between 21 and 99 feet deep;
— in silty to clayey soils (soils studied were gravelly or rocky, sandy, silty or loamy and clayey); and,
— more than 30 feet from crop land.

Wells at the other end of each spectrum were most likely to provide water with low nitrate-N levels.

The wells with more than 10 mg/L averaged 52 years old. For wells over 70 years old, 83 percent had nitrate-N exceeding 10 mg/L. Of those less than 30 years old only 25 percent exceeded the health standard.

Of those wells within 100 feet of a potential source of organic contamination, 37 percent exceeded the EPA health advisory. However, another 33 percent yielded water with less than 4 mg/L of nitrate-N. A closer examination of the data revealed that for wells with greater than 20 mg/L of nitrate-N, a source of potential organic contamination was a more likely contributing factor.

Wells with a depth of 21 to 50 feet had the highest concentration of nitrate-N. The finding of greater nitrate-N concentrations in silty to clayey soils was unexpected and suggests that factors other than soil texture had more dominant influence on nitrate concentrations. Analysis of well construction did not reveal any important differences in nitrate concentration between dug, driven, or drilled wells. Here again, any real differences in influence may have been obscured by other more dominant influencing factors.

The study also reported the following:

Locating wells in cropland areas decreases slightly the likelihood of very high nitrate levels...wells within 30 feet of cropland had a lower average concentration of nitrate-N and a lower percentage of those in and near croplands exceeded 20 mg/L. This would indicate that cropland and associated fertilization is not the most important source of nitrate in farmstead wells. While fertilization might increase the overall background value of nitrate in groundwater, the level of concentration that results is likely to be less than the MCL. Point sources of nitrate are more likely to be the cause of higher nitrate-N concentrations.

The latter seems to be a very important observation and interpretation and should be further evaluated through more powerful sample designs and analytic tools to ensure the results of this Kansas study are not spurious.

Minnesota Analyses. In 1988 Faribault, Martin, and Watonwan Counties at the southern border of Minnesota conducted a water quality assessment and education program under the sponsorship of the Minnesota Extension Service, the local soil and water conservation districts, and the USDA Soil Conservation Service (FMW Water Project, 1988).

The assessment included the sampling and testing of 340 wells in all three counties for nitrate, bacteria, and sulfates. Twenty-two percent of tested wells had detectable levels of nitrate; nine percent tested above the HAL of 10 mg/L. The correlation of the nitrate data with the type of well casing, well dept, and well age was analyzed. Only the type of casing was strongly correlated with nitrate occurrence; 65 percent of the wells with concrete tile casings and 73 percent with clay tile casings tested positive for nitrate. By comparison, only 8 percent of the wells with steel casings and 18 percent with plastic casings tested positive for nitrate. Only 5 percent of the 340 wells sampled tested positive for bacterial presence. High bacterial levels were considered usually to result from the decay of some organic matter decay in the well. Quite frequently, positive levels of bacteria were associated with positive levels of nitrate. The report hypothesized that animal waste may have been the source of both nitrate and bacterial contamination in the well water.

For 245 water samples collected during 1984 to 1986 from 56 wells at 45 sites in surficial sand-plain aquifers underlying 600 square miles in 4 counties of west-central Minnesota, the mean nitrite-plus nitrate-N concentrations varied with intensity of agricultural cultivation, as follows (Anderson, 1989):

Intensity of Cultivation	Mean nitrite-plus nitrate-N level
Uncultivated natural areas	4.3 mg/L
Nonirrigated cultivated areas	5.4 mg/L
Irrigated cultivated areas	17.0 mg/L

The mean nitrite-plus nitrate-N concentration in uncultivated areas was greater than usually observed background levels of < 1 mg/L. That may indicate that areas considered natural actually are influenced by agricultural land use. Several statistical tests also indicate that concentrations in irrigated cultivated areas are significantly higher than concentrations in nonirrigated areas. The latter indicates that nitrate fertilizer is being leached during heavy rainfall or irrigation periods due to higher nitrate fertilizer levels being maintained in the irrigated soil to enhance corn and potato yields (Anderson, no date).

Another study monitored ground water in a 10-square-mile area of the Upper Minnesota River Watershed District (UMRWD) to better understand how local hydrology and land use affects well water contamination by nitrate (Wall and Magner, 1988). Between May 1987 and September 1989 groundwater samples were collected six times in 19 wells developed in surficial outwash, buried outwash and cretacious aquifers under irrigated corn, small grain, pasture, grassland, and farmstead land uses. Nitrate was the primary pollutant found in the study. Nitrate-N levels above the 10 mg/L drinking water standard were found in 10 out of 15 wells that were less than 50 feet deep. The highest nitrate-N concentrations (43 to 105 mg/L) were found in a 20-foot well that was downgradient from an irrigated corn field. At the same site a deeper well that also penetrated a layer of till had consistently low nitrate-N concentrations (< 2 mg/L). The till apparently acted as a barrier to further downward movement of nitrate at this site. At another location, 1.5 miles from this site and likewise downgradient from irrigated corn fields, nitrate-N levels in a shallow, 16-foot well ranged from 22 to 33 mg/L as compared to 6-19 mg/L levels found in a deeper, 43-foot well. Strikingly different calcium/magnesium ratios in the latter two wells indicated that the water in the deeper well was coming from somewhere upgradient from the wells rather than through the till layer directly above.

Elevated nitrate levels were found under most areas of the UMRWD project, even under areas that had been fallow for 10 years. The study findings suggested that ground water from high nitrogen fertilizer inputs on irrigated corn fields was moving laterally and contributing to high nitrate levels in wells 1 to 2 miles downgradient. One well showed 34 to 53 mg/L of nitrate while chloride was increasing from 43 to 78 mg/L through the project life; that well was suspected of septic system contamination. The latter finding suggested that agronomic nitrate contamination was probably being compounded in some places by septic system contamination.

Nitrate concentrations in wells sampled in the UMRWD project had great temporal and spacial variation. Some wells showed rising nitrate-N levels while others showed falling levels during the testing period. For one domestic farm well, nitrate-N dropped from 30 mg/L in June 1987 to 1 mg/L in March 1988.

Four sampled wells over 100 feet deep all had nitrate-N at less than 1 mg/L. Age-dating indicated these wells held older water (e.g., > 35 years old). However, high-capacity pumping from a 462-foot irrigation well was drawing somewhat younger water from overlying aquifers downward. Thus, the pumping of deep wells could be a source of contamination: deeper aquifers might be contaminated by nitrate originating in overlying aquifers.

Pennsylvania Analyses. Research was undertaken in Pennsylvania to evaluate the impact of nitrogen fertilization on the accumulation of nitrate-N in the soil and its potential for contaminating surface waters and ground water (Roth and Fox, 1990). Nine experimental areas were evaluated in central and southwestern Pennsylvania for nitrate-N accumulation in the surface 120 centimeters of soil after crop harvest for: (a) various fertilization rates, (b) estimation of nitràte-N accumulation at the economic optimum nitrate, and (c) change in nitrate- N accumulation over winter. The following tabulation summarizes the nitrate-N accumulation and the estimated amount of nitrate-N in the soil water solution at field capacity (when 31 percent of the soil volume is occupied by water):

Experiment	Economic Optimum Nitrate-N	Soil Nitrate-N Accumulation [1/]	Estimated Soil Solution of Nitrate-N
	kg/ha	kg/ha	mg/L
Unmanured plus N			
1	103	66	17.2
2	51	100	26.0
4	179	82	21.3
8	156	46	12.0
9	100	74	19.3
Manured plus N			
3	85	93	24.2
6	48	95	24.7
Manured w/o N added			
5	0	139	36.2
7	0	198	51.5

[1/] Accumulation was estimated using a regression equation fitted to accumulation data from 3 to 5 N levels tested in each experiment.

The soil solution nitrate-N concentration at field capacity, estimated at the economic optimum level of N application, averaged 24 mg/L for the nine experiments and exceeded the 10 mg/L HAL in each experiment. These data indicate there is considerable potential for leachate from the experimental fields to exceed the 10 mg/L HAL for at least part of the year when fertilized at the economic optimum N rates. No significant differences were found between spring and fall accumulations of soil nitrate with fertilization rates at or near the economic optimum levels of nitrogen application.

The relationship between soil solution concentrate and actual leachate concentration was not determined or known in these experiments. Therefore, additional data are needed on the fraction of soil nitrate-N that is susceptible to leaching and on the dynamics of this relationship throughout the year to determine leachate concentration at economic optimum nitrate-N rates. These findings indicate that best management practices that reduce nitrogen applications to economic optimums may not reduce nitrate soil accumulations enough after harvest to bring leachate nitrate-N concentrations below the 10 mg/L HAL.

Similar studies conducted by the Agricultural Research Service, USDA on the Eastern Shore of Maryland are producing the same general findings and conclusions, but the results are not yet published (Meisinger, 1991).

South Dakota Analyses. Charles H. Ullery, Extension Water and Natural Resources Specialist in South Dakota, summarized the results of monitoring nitrate in ground water for five water quality monitoring projects between 1969 and 1989 (Ullery, 1990). The impacts of implementing best management practices (BMP's) at the 106,000-acre, 10- year Oakwood Lakes-Poinsett Rural Clean Water Project were evaluated for 1984 to 1988. One of the objectives was to reduce through conservation tillage, fertilizer application, and livestock waste BMP's the nonpoint source of total nitrogen entering surface and ground water. Some 114 wells located in shallow sand/gravel outwash and glacial till were monitored. Depths of the monitoring wells ranged from 7 to 60 feet, with water samples collected from the top to 45 feet below the water table on a monthly to quarterly basis. Out of 1,876 samples analyzed for nitrate from 1984 to 1988, 32 percent, all collected at depths less than 20 feet below the water table, showed levels of nitrate-N greater than 10 mg/L. Since good fertilizer management was used at all monitoring sites, it was not possible to compare poor and good fertilizer management. However, the median nitrate level for all farmed sites was significantly higher than for one nonfarmed site.

During 1978 to 1983 a comprehensive base study of the shallow, 1,000- square-mile Big Sioux aquifer was conducted to determine existing and potential water quality threats to a third of the South Dakota population served by this aquifer. In addition to sampling the wells of six large public water supply systems, this study collected water samples from monitoring and private wells located throughout the aquifer area. Although the natural nitrate-N levels for the aquifer were less than 2 mg/L, 37 percent of the sampled private wells had nitrate-N exceeding 10 mg/L. In contrast, only 5 percent of the monitoring wells located away from residences showed more than 10 mg/L. Thus, it is reported that most cases of excess nitrate-N in private wells were of "point source origin and the result of improper well location and construction coupled with livestock feedlots, domestic septic disposal systems and other source of nitrates near the wellhead locations." A separate analysis of 1,037 water samples taken by private individuals in the study area and tested by the State health laboratory showed 27 percent had more than 10 mg/L of nitrate-N. General nonpoint source contamination by nitrate fertilizers or livestock waste was not seen as a current general problem in the aquifer. However, it was suspected as occurring in several small areas or "hot spots."

During 1988 and 1989, the Parker-Centerville aquifer was selected to determine the presence and extent of nonpoint source nitrogen fertilizer contamination. The aquifer was selected for its relative susceptibility to contamination due to its shallow depth to the water table (10 feet), the high usage of fertilizers with irrigation, and high crop yields. Historical data for nonirrigated parts of the aquifer indicated a natural nitrate-N level of less than 1 mg/L. Ten monitoring sites were selected to avoid potential point sources of contamination. In addition, 2 or 3 wells were put in at each site to sample water from different depths (total of 24 wells). The results of sampling and testing for nitrate-N were as follows:

Year	Wells Sampled	Nitrate-N Level in mg/L		
		<5	5 to 10	>10
	Number	Percent of Wells		
1988	126	67	27	6
1989	126	86	14	0

No effort was made to compare fertilizer use with observed nitrate levels, but nonpoint sources were thought to be the source of any measured contamination.

Another study similar to the Parker-Centerville aquifer study was conducted for the same purposes in the Bowdle aquifer in 1989. It also had a natural background nitrate level below 1 mg/L. Monitoring was at 7 sites free of potential point sources of contamination with 1 or 2 wells per site (total of 10 wells). The water table was 6 to 10 feet deep. Of a total 60 nitrate samples collected over the year, 37 percent had more than 10 mg/L of nitrate-N; 18 percent had 5 to 10 mg/L and 45 percent had less than 5 mg/L. Although there was no analysis of the source of elevated nitrate levels, the source was thought to be nonpoint fertilizer use.

The South Dakota Health Laboratory annually analyzes 2,000 to 5,000 thousand water samples from water wells on a fee basis. Individuals must submit samples in special bottles according to specific instructions. During the last two decades 20 to 30 percent of the samples submitted each year contained more than 10 mg/L of nitrate-N. Although no effort was made to determine the contamination source for each problem sample, studies and investigations indicated that the vast majority of wells were contaminated at the wellhead.

The Occurrence and Influence of Denitrification

Denitrification is a process carried out by micro-organisms in soil or soil water that converts nitrate to nitrogen in its gaseous from and returns it back to the atmosphere. Denitrification takes place under saturated or wet conditions when the soil is deficient in oxygen—or anaerobic—and sufficient carbon for energy is available from organic materials.

Denitrification has traditionally been viewed as an undesirable process among agriculturists due to the loss of nitrate from the soil. In recent years, it has received attention due to its potential beneficial role in reducing the N content of soil water below the crop rooting zone that is leaching into ground water (Gambrell et al., 1975).

A 1990 groundwater study in Nebraska's Lower Platte Valley substantiated the occurrence of denitrification in very shallow water-table areas. It also uncovered a potential pitfall of relying on generalized vulnerability models to identify areas of potential contamination. The ground water in Douglas County between the Platte and Elkhorn Rivers was assessed as highly vulnerable to contamination using DRASTIC methodology. DRASTIC is an index that permits analysts to rate an area's vulnerability to groundwater contamination on the basis of selected hydrological characteristics of the area. Although the depth to water was less than 2 meters and the area was cropped to irrigated corn, nitrate-N levels exceeded 7 mg/L in only 3 of 15 irrigation wells. The isotopic ratios were highly fractionated (+14 to +32 percent), suggesting a high level of denitrification. Nitrate-N levels in the other wells were generally less than 5 mg/L, and were less than 2 mg/L for the majority. The occurrence of trace levels of atrazine in 10 irrigation wells tested for atrazine indicated favorable conditions for leaching of agrichemicals. Spalding and Exner also report that even though denitrification in Douglas County water-logged, irrigated soils controls the amount of nitrate leaching to ground water, some evidence showed that the aquifer itself was slightly reducing so that denitrification could occur in ground water.

Spalding and Exner observed that even though vulnerability models predicted that areas with potential nitrate sources in the Southeast, the eastern Corn Belt, and parts of the Great Plains were vulnerable to contamination, there was little or no documented nitrate contamination. They concluded that in these areas denitrification attenuates the impact of nitrate leachate to varying degrees.

In recent years water table management through controlled subsurface drainage and subirrigation has taken advantage of the denitrification process to reduce the movement of nitrogen to surface and ground water. The idea is to maintain the water table at varying depths above the drain tile during the growing season but particularly in the period between harvest and spring tillage. This practice manages the saturated soil depth between the tile and the soil surface to promote denitrification and subsequently reduce nitrate loading on surface water. Maintaining nitrate loadings during the "off-season" does not preclude equipment operations during the growing season since drainage controls can be adjusted in time to drain the soil sufficiently for spring tillage and planting. Depending on the actual field cropping and management practice, water level could be managed to various depths in the growing period, e.g., immediately below the rooting zone, to reduce nitrate loading even in that period (Brown et al., 1989). Various studies completed in Iowa since 1985 indicate that optimum water table management practices can result in lower nitrate concentrations in subsurface drainage discharges and improve both surface and ground water quality (Kanwar, 1990). Studies in North Carolina indicate controlled subsurface drainage may reduce nitrate-N concentrations in drainage discharges by up to 20 percent compared to no control drainage systems (Evans et al., 1989).

Executive Summary

The EPA standard for nitrate-N in drinking water is set at 10 mg/L to protect babies under about 3 months of age, the most nitrate-sensitive segment of the U.S. population. Such infants are much more sensitive to nitrate toxicity than the rest of the population for a variety of reasons. For example, bacteria that live in the digestive tracts of such infants convert nitrate into toxic nitrite. Nitrite transforms hemoglobin to methemoglobin, preventing transport of oxygen and producing symptoms of asphyxiation (blue-baby syndrome). After babies reach an age 3 to 6 months, acid in their stomachs increases, thereby creating an unfavorable environment for the bacteria causing the problem.

Infant methemoglobinemia has decreased considerably in recent years. Some 278 cases between 1939 and 1950 resulted in 19 deaths. In North America and Europe combined, 2,000 cases were documented between 1945 and 1971. Seven to eight percent resulted in infant deaths. Since 1960, with increased awareness within the medical profession in diagnosing the symptoms, there has been one documented death by methemoglobinemia in the United States, and it was apparently related to farmyard sources of nitrate contaminating well water. Other potential health impacts from nitrate in water (stomach cancer for example) are suspected by some scientists and health and regulatory interests but have not been proven conclusively.

Methemoglobinemia in Infants

The drinking water standard for nitrate set for the United States by the Environmental Protection Agency is 10 mg/L, measured as nitrate-nitrogen or its equivalent 45 mg/L measured as nitrate. The standard is set to protect the most nitrate-sensitive segment of the U.S. population: Babies under 3 months old and particularly those affected by diarrhea. Babies in this age group are extremely susceptible to acute nitrite poisoning because of certain bacteria that may live in their digestive system during their first few months of life. Bacteria are present in young infants because of high stomach pH. These bacteria change nitrate into toxic nitrite, transforming hemoglobin (which carries oxygen to all parts of the body) to methemoglobin which does not carry oxygen. As the oxygen carried by the blood decreases, the body is suffocated. This condition is called infant cyanosis or methemoglobinemia (blue-baby syndrome). At 3-6 months of age, hydrochloric acid levels in the baby's stomach increase and kill most of the bacteria that convert nitrate to nitrite.

For infants less than 6 months old, the 10 mg/L standard represents a 10-day health advisory level. The corresponding 10- day health advisory for all other groups is 111 mg/L of nitrate-N. While most infants can apparently tolerate nitrate-N in water at levels much higher than 10 mg/L, other, more susceptible infants can begin to exhibit symptoms at levels only slightly higher than 10 mg/L. For adults, the 10 mg/L standard is a lifetime health advisory level (Baker et al., 1989).

Cyanosis symptoms are easily recognizable and require immediate medical attention. Methemoglobinemia is readily treated and the condition is rapidly reversible without any known or research-based cumulative effects. Nitrite poisoning can be treated, and in most cases, the baby can experience full recovery. Because there are other causes of cyanosis, it is desirable to diagnose a sample of the infant's blood to confirm actual methemoglobinemia before treatment.

Clinical reports of methemoglobinemia in the United States have been virtually nonexistent in recent years (Keeney, 1986). In 1971, E.F. Winton reported that about 2,000 cases of infant methemoglobinemia had been recorded in North America since 1945, with 7 to 8 percent resulting in fetal death. L.A. Shearer states there were no fatal cases of methemoglobinemia in the United States from 1960 to 1972. A similar study in 1988 reported that doctors serving in maternity wards of Nebraska hospitals had encountered only 33 cases of methemoglobinemia— with no recorded fatalities (Sandstedt, 1990).

In a survey of 353 physicians in the 10-county Big Sioux region in eastern South Dakota in 1982, 29 physicians reported having treated about 64 cases of methemoglobinemia before 1972 and 16 cases since 1972. All but one case occurred in infants (Johnson et al., 1987). One infant death reported in South Dakota in June 1986 has been tentatively linked with nitrogen fertilizer applications (Des Moines Register, 1986). The mother reported blueness symptoms to the family physician during the 1- month-after-birth checkup; the physician attributed the symptoms to room temperature changes.

Three weeks later a pharmacist suggested the infant may not be getting enough oxygen. Another week later, when the child had severe cyanosis and diarrhea with vomiting, the physician gave the infant oxygen without any improvement. Noticing a heart murmur, he referred the family to a hospital for further treatment. The infant died en route. Later, the well water at the farm was found to have a nitrate-N level of 150 mg/L (Johnson et al., 1987).

Another case reported in South Dakota in 1982 involved a 6-week-old infant fed on formula from well water (later found to contain 121 mg/L nitrate-N). The symptoms rapidly disappeared when well water was replaced by bottled water (Keeney, 1986). Infant exposure is through ingestion of tap or well water directly or in formula mixes. Breast-fed infants are at lower risk than formula-fed infants because nitrate does not appear to be transferred to infants in breast milk (Wade Miller Associates, 1990). The use of purchased bottled water in place of tap or well water can similarly reduce risk to formula-fed infants.

Infant deaths from methemoglobinemia now are very rare because doctors recommend the use of bottled water where the nitrate-N content of water exceeds the public health standard of 10 mg/L. In Iowa, for example, where the cause of the disease was first associated with well water of high nitrate content in 1945 (Comly, 1945), no infant deaths from methemoglobinemia have been reported since 1948. The public health standard was set many years ago as the concentration below which no cases of infant methemoglobinemia had been identified (Cast, 1985).

Other Effects

Nitrate itself is not directly carcinogenic. However, there is recognition that nitrate could be converted to nitrite in the human body and react with secondary and tertiary amines to form nitrosamines— which have been identified as potent carcinogens in numerous animals and which could be carcinogens in humans. Normally the stomachs and upper intestines of older infants, children, and adults are acidic. This inhibits the growth of bacteria that could convert nitrate to nitrite. Thus, nitrate is absorbed into the blood stream as nitrate, and excreted in the urine in that form before the contents of the digestive tract reach the lower intestines which are less acidic and support bacteria that could convert nitrate to nitrite. Although there are many studies on the questions about the carcinogenic effect of nitrate, including a number of epidemiological studies that demonstrate correlations between several different cancers and nitrate intake, there is no conclusive evidence linking cancer incidence of any type to nitrate in drinking water (Keeney, 1986 and Parry, 1991).

There is some evidence from rat feeding trials that subclinical neurosystem damage can occur due to ingestion of high-nitrate water. Results of these studies, however, have not been confirmed. There also are studies that have investigated the possibility of reproductive or developmental effects of nitrates in drinking water, but they are not considered sufficient to discern a relationship between nitrate and congenital malformations (Keeney, 1986 and Parry, 1990a).

Question 4. What Is Known About the Environmental and Livestock-Related Effects of Nitrate in Water?

Executive Summary

In addition to the potential problem of groundwater contamination by nitrate, excess nitrate may have other adverse effects on the environment.

Nitrate is recognized as a factor in eutrophication in the fresh and saline waters of estuaries where over-enrichment may lead to reduction of dissolved oxygen concentrations and adversely impact finfish and shellfish populations. Low concentrations of dissolved oxygen have been identified in about 15 Atlantic and Gulf coast estuaries and in Puget Sound.

Nitrate in estuaries reflects all sources, point and nonpoint as well as urban, rural and atmospheric sources. The extent to which agriculutral sources contribute to estuary loadings is generally not known. Nitrous oxide (N2O) from soil nitrogen transformation has been identified as a contributor to the depletion of stratospheric ozone and to global warming. Some acid rain carries HN03 (nitric acid) but most of this comes from high-temperature combustion. The contribution from agricultural sources is relatively small.

Nitrate can become toxic to ruminants, horses, and baby pigs when it is reduced to nitrite by bacteria in the digestive system. In a healthy animal with a properly functioning system, the nitrite is further reduced to ammonium and used in protein synthesis. When concentrations of nitrate are excessive or animal health is poor, the toxic nitrite may cause methemoglobinemia. The tolerance level of livestock (40 mg/L of nitrate-N) is higher than for human infants. Nonlethal doses of nitrate also have been associated with multiple abortions in cattle.

Environmental Effects

It is generally accepted that nitrate is a limiting factor on eutrophication in fresh and saline waters of estuaries. Overenrichment may lead to reduction of dissolved oxygen concentrations. Estuaries make up less than 1 percent of the ocean environment, but they are the most productive part. Their productivity is the result of nutrient cycling that supports phytoplankton growth. Nitrogen is an essential nutrient for the growth of aquatic plants and generally stimulates the productivity of an estuarine system. However, excess discharges of nitrate into estuaries often lead to eutrophication. The most visible effects of eutrophication are the massive blooms of phytoplankton. The decay of excessive algal blooms as they die off and sink can lead to depletion of dissolved oxygen and cause hypoxia in bottom waters. Hypoxia is a condition that occurs when dissolved oxygen in bottom waters is less than 2 milliliters per liter. This condition can lead to mass mortalities of finfish and shellfish. The most recent case in the Northeast occurred in Long Island Sound in the summer of 1987. Nutrient enrichment, combined with high temperatures, resulted in massive blooms of phytoplankton, bottom waters devoid of dissolved oxygen, and largefish kills. The flushing rate, circulation, and wind field are all important factors influencing the duration, magnitude, and extent of eutrophic conditions induced by nutrient loadings in estuaries (NOAA/EPA Team, 1988). Also, the nitrogen to phosphates ratio may be more important than the absolute level of either nutrient since phytoplankton require nitrogen and phosphorus in the approximate ratio (atomic) of 16 to 1 for growth (NOAA/EPA Team, 1989).

The tolerance of marine environments to nitrogen is less than that for fresh waters where one mg/L of nitrate-N is regarded as indicative of good ecological conditions. The condition indices calculated for Chesapeake Bay waters, for example, are as follows: [1/]

Conditions	Nitrogen-N in mg/L
Healthy and High Water Quality	<0.6
Fair	0.6-1.0
Fair to Poor	>1.0-1.8
Poor	>1.8

[1/]Source: NOAA by telephone.

These condition indices apply to the tidal fresh waters of the Bay with salinity levels from 0 to 0.5 ppm. For waters with higher salinity levels, nitrogen is more limiting and the optimal nitrogen level is much lower than 0.6 mg/L.

Low dissolved oxygen concentrations have been identified in the following estuaries:

East Coast	Gulf Coast
Long Island Sound	Tampa Bay
East River	Pardido Bay
Hudson/Raretan Bay	Mobile Bay
N.Y. Bight/Coastal N.J.	Lake Pontchartrain
Chesapeake Bay	Central Gulf of Mexico
Lower Chowan River	
Albemarle Sound	**West Coast**
Neuse River Estuary	
Biscayne Bay	Puget Sound

Nitrate in estuaries reflects all sources, point and nonpoint as well as urban, rural, and atmospheric sources. The agricultural contribution generally has not been quantified. There are a few efforts where estimates have been made. For example, calculations made for Chesapeake Bay nutrient management under the Tristate Chesapeake Bay Agreement indicate that 67 percent of the nitrogen entering the Bay originates from nonpoint sources, with agricultural cropland producing a large portion of that loading (EPA, 1990d).

Nitrate can stimulate eutrophication in lakes, but phosphorus is considered the more common and more critical limiting nutrient on lake eutrophication. As with estuaries, the nitrogen to phosphorus ratio in lakes may be more important than the absolute level of either nutrient.

The production of N20 from nitrification and denitrification resulting from increased use of fixed nitrogen has been identified as a contributor to the depletion of stratospheric ozone. However, according to recent estimates, the potential impact is so small that "the current value to society of these activities that contribute to global N fixation far exceeds the potential cost of any moderate...postponement of action to reduce the threat of future ozone depletion by N20" (National Research Council, 1978).

The acidity of acid rain is due largely to strong mineral acids (H2S04, HN03, and a minor amount of HCL). The relative contribution from HNO3 has increased with time. The contribution from agricultural sources, however, has not been quantified. The material damage and ecological effects of acid rain are difficult to assess.

Phytotoxicity from N02 in alkaline soils treated with urea or NH3 fertilizers has been observed to depress plant growth. However, it is not an important agronomic problem.

Livestock-Related Effects

Nitrate can become toxic to ruminants, horses, and baby pigs when it is reduced to its unstable nitrite state by bacteria in the digestive system. If the system, e.g., the rumen in cattle, is functioning properly and the animal is in good health, the unstable toxic nitrite will be immediately reduced to ammonium and stored for potential use in protein synthesis.

However, if too high a nitrate concentration is consumed or the animal is in poor health or the rumen is not functioning properly, it is possible for the nitrite to increase faster than its rate of conversion to ammonium. The accumulating toxic nitrite may be expelled harmlessly through the urine, or it may be absorbed through the lining of the intestine into the bloodstream and cause methemoglobinemia, as it does in infants less than three months old. The problem is readily reversible with veterinary assistance and injection of methylene blue.

The tolerance level of livestock to nitrate-N in water is higher than the health standard for humans. As much as 40 mg/L may be safe or tolerable providing feed does not contain more than 1,000 ppm of total nitrate. Rates of 40 to 100 mg/L are risky unless the feed is low in nitrate and fortified with vitamin A. Water with 100 mg/L or more should not be used and acute poisoning and some deaths are likely with over 200 mg/L (Sandstedt, 1990).

A few cases have been documented where nonlethal doses of nitrate have been associated with multiple abortions in herds of cattle diagnosed as having nitrate toxosis. These cases and some studies suggest that chronic nitrate toxicity must be considered a potential threat to a herd's reproductive capability, especially where such herd abortions are repeated over 2 or more years (Sandstedt, 1990).

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